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Abstract

The effect of progressive taxation policies on the economy has been an issue of extensive debate in recent decades. This research paper employs the standard Bewley-Hugget-Aiyagari (BHA) heterogeneous-agents DSGE model with some extensions to provide a general analysis of the Nicaraguan economy regarding the effectiveness of progressive taxation policies to reduce inequality. The baseline model is consistent with the standard literature and properly resembles a realistic distribution of consumption across the agents and the aggregate components in the Nicaraguan economy for 2014. The analysis provides evidence of the effectiveness of progressive taxation as a tool for reducing inequality in consumption and income across all agents in the economy; in addition, it is highlighted that this progressive structure needs to be updated periodically to considerate the discrepancies between the evolution of real and nominal wages, so the efforts on reducing inequality are not mitigated.

Keywords: Progressive taxation, Heterogeneous agents model, Nicaragua, Inequality.

JEL codes: C68, E62, H21, H30, I31.

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1 Introduction

Inequality has been a topic of high interest in recent decades, and it has gained more relevance as it has increased considerably in most of the economies in the world. The concern about this increase has led to a heated debate over different calls for redistribution through the implementation of various policies[1], with the main attention directed to progressive taxation as a tool for reducing inequality.

Although progressive taxation has been considered an effective tool for reducing inequality, governments have historically been reluctant to aggressively implement such policies, perhaps due to their effectiveness costs on macroeconomic aggregates. According to Auerbach & Kotlikoff (1987*a*), a progressive tax has at least two characteristics: (1) average tax rates increasing with the size of the tax base, and (2) marginal tax rates greater than average tax rates. Such characteristics imply that progressive taxation is distortionary and imposes efficiency losses in terms of production.

Consequently, the collateral impact of progressive taxation policies on the aggregate economy has been extensively discussed in recent decades. Auerbach & Kotlikoff (1987*b*) found that switching from proportional to progressive taxation can significantly decrease long-run capital formation and aggregate output and consumption. Similarly, Heathcote et al. (2016) pointed out that governments are hesitant to push progressivity too far because of distortions to labor supply and skill investment[2].

Despite all the arguments against progressive taxation policy and its distortionary effects on the aggregate economy, developing economies have extensively used it as an effective tool to fight against their characteristic high inequality conditions. According to Martorano (2018), Latin American countries have promoted tax changes, specifically, those progressive tax systems that contribute to inequality reduction.

Based on these observations, this research paper seeks to provide an analysis for the Nicaraguan economy regarding the effectiveness of progressive taxation policies to reduce inequality. To analyze this matter,

[1]For instance, from the work of Pikett & Saez (2003), one can argue that social norms, labor market institutions, and fiscal policy are crucial determinants of inequality, and that changes in inequality are highly driven by variations in capital income.

[2]Other authors that have worked on the distortionary effects on labor supply and skill investment include Heckman et al. (1998), Krueger et al. (2013), and Guvenen et al. (2014).

we consider the heterogeneous agents model developed by Aiyagari (1994), Bewley (1986), and Huggett (1993), with extensions proposed by Domeiji & Heathcote (2004) and Heathcote (2005) on the productivity shocks process. In our model, households differ endogenously in terms of their labor income composition and the level of assets they hold, due to idiosyncratic and uninsurable productivity shocks that affect the income households perceive.

It is pertinent to mention that some efforts have been previously made to develop Dynamic Stochastic General Equilibrium (DSGE) Models for Nicaragua. First, Gámez (2010) proposed a Computable General Equilibrium Model (CGE) to determine the effects of economic policies and external shocks over the different sectors of the economy. Subsequently, Flores Sarria (2013) proposed a New Keynesian DSGE model to evaluate the impact of internal and external shocks in Nicaragua between 1994 and 2011, while Miranda (2022) analyzed the dynamics of business cycles in Nicaragua through a Real Business Cycle (RBC) model focused on productivity shocks.

Perhaps the most closely related work to our framework is that of Acevedo (2011). The author evaluated the impact of tax reforms in Nicaragua using a DSGE model for a closed economy with a representative agent and three types of taxes (labor income, consumption, and capital income). The results contributed to a better understanding of how tax reforms have affected the government balance; however, the author highlighted some limitations on replicating the dynamics of certain variables due to the small sample size and the tax system complexity.

Although valuable for understanding the dynamics in the economic aggregates of Nicaragua, the DSGE models proposed until now lack the important characteristic of heterogeneity across agents in the economy, which is important mainly for two reasons: (1) models with heterogenous agents have a more realistic resemblance of the conditions of any economy compared to those models with a representative agent assumption, and (2) heterogeneity enables the analysis of the effects of policies and shocks on inequality and redistribution.

To properly assess the quantitative implications of progressive taxation on inequality and the aggregate variables of the economy, we perform experiments in which we assume the economy is initially in a steady state, characterized by a progressive labor income tax, and unexpectedly, the government decides to implement a policy changing the current conditions of the taxation structure for labor income.

The first experiment considers a shift to a linear tax scheme where all agents face the same tax rate, aiming to evaluate the current system's effectiveness in reducing inequality. The second experiment imposes a tax rate increase on lower-productivity agents to analyze the current scheme's rigidity in light of the evolution of nominal versus real wages. The rigidity of the current tax system in Nicaragua stems from the fact that nominal tax brackets have not changed since 2012.

Specifically, in an inflationary environment, an agent's real disposable income can be eroded by the tax system even if their real pre-tax wage remains constant. Although our model does not explicitly consider nominal variables, we simulate this mechanism by assuming a real tax increase for lower-productivity agents, as explained in more detail in the Results Section.

After conducting these experiments, we documented and analyzed the effects of these policies on the aggregate variables of the economy and the distribution of households in terms of income, consumption, and wealth. Additionally, the analysis includes transitional dynamics to study in detail the short-run implications of the first experiment.

The calibration strategy of the baseline model (i.e., the initial steady state) is designed to ensure that the redistribution of the total income tax burden under the initial progressive taxation scheme is realistic and accurately reflects the characteristics of the Nicaraguan economy. Specifically, the model effectively mirrors the distribution of consumption in Nicaragua in 2014, as well as key features related to the distribution of income and wealth.

The main findings of our work highlight the effectiveness of progressive taxation as a tool for reducing inequality in consumption across all the agents in the Nicaraguan economy. Additionally, the progressive tax system reduces inequality in income when compared to a linear tax system but has no significant effects on the redistribution of wealth.

Regarding the effects on the aggregate economy, we found that moving from a progressive to a linear tax system does not improve the production level of the economy, since the output does not experience a significant increase. This happens because agents in the economy who perceive a higher disposable income due to the change decide to consume almost all their extra income instead of saving to build future production capacity. These findings suggest that progressivity is the most appropriate tax system for economies with conditions similar to the Nicaraguan economy.

We also found that, due to the nominal rigidity of the current tax system, non-high-productive agents suffer a loss in their disposable income due to higher taxes to pay when they do not experience any increase in their real incomes. These losses in disposable income exacerbate the inequality conditions in consumption and income and mitigate the positive effect progressive taxation has over the distribution of total consumption and income.

Finally, the transition dynamic analysis showed that almost all the variables had a smooth transition toward their new steady-state level. The only exceptions to this were aggregate consumption and its inequality, which jumped up immediately after the change was announced because of the effect of the tax burden distribution. It was also found that it takes at most 10 years for the economy to reach at least 90% of the new steady-state level.

The structure of the paper is organized as follows. Section 2 outlines the specifications of the proposed model, which incorporates heterogeneous agents and idiosyncratic and uninsurable productivity shocks, as well as the calibration to match the Nicaraguan economy. Section 3 presents the main quantitative results from our experiments. Finally, Section 4 concludes.

2 Model

We consider the standard model developed by Aiyagari (1994), Bewley (1986), and Huggett (1993), with an extension[3] proposed by Domeiji & Heathcote (2004) and Heathcote (2005). The economy is populated by a continuum unit mass of infinitely lived and heterogeneous households that face idiosyncratic and uninsurable income shocks.

There is one type of good in this economy which can be either consumed or saved in the form of future capital. Firms use labor and capital as inputs to

[3] The main extension considered is the household productivity process, which remains consistent with the results estimated by Flores Sarria (2013) for Nicaragua and with the standard estimations found by Flodén & Lindé (2001).

produce and optimize profits given prices in a competitive factor market; in addition, there is no aggregate uncertainty, and the model is solved under perfect foresight.

The Government in this economy issues debt in the form of one-period risk-free bonds which are perfect substitutes for capital assets; in addition, it consumes a proportion of the total output and collects taxes on asset income, consumption, and labor income to finance its spending and the payment of interest on its total debt (where government debt is assumed to be a constant proportion of the total output).

Before the Government implements any tax reform, we assume the economy is in the initial steady state with no uncertainty (i.e., a state characterized by progressive income tax rates), and from this point on, we study the effects after implementing different and unanticipated changes[4] in the prevalent labor income tax scheme of the economy.

2.1 Households

Every household chooses between consumption c_t and saving $s_t = a_{t+1}$ to maximize their lifetime expected utility, which is given by the following expression:

$$E_0 \sum_{t=0}^{\infty} \beta^t U(c_t) \tag{1}$$

Subject to:

$$(1+\tau_c)c_t + a_{t+1} = [1 + (1-\tau_k)r_t]a_t + (1-\tau_{\bar{n}}(\bar{e_t}))\omega_t e_t \bar{n} \tag{2}$$

$$a_{t+1} \geq 0 \tag{3}$$

Where $\beta \in (0,1)$ is the discount factor for the utility function $U(c_t)$; τ_c, τ_k, and $\tau_{\bar{n}}(\bar{e_t})$ are the tax rates on consumption, asset returns, and labor income, respectively; r_t is the pre-tax real interest rate; ω_t is the wage per unit of effective labor; $\bar{n}$ is the amount of effective labor supply per period (which is assumed to be perfectly inelastic and equal for all households in this economy); and e_t is the idiosyncratic and uninsurable productivity

[4]Specifically, one change from progressive to a linear taxation scheme, and another change where the medium and low productive agents pay more taxes on labor income.

shock that follows a first-order Markov process with transition probability defined by the matrix $\Pi_p(e_{t+1}|e_t)$. Also, notice that equation (3) imposes a non-borrowing restriction for agents in this economy[5].

From these three equations, one can notice that the solution to this household's problem is the set of choices for c_t and a_{t+1} such that, $\forall t$ and $\forall e_t \in E_t$, they maximize equation (1), subject to (2) and (3), and given τ_c, τ_k, $\tau_n(\bar{e_t})$, and the sequences of values $\{r_t\}_{t=0}^{\infty}$ and $\{\omega_t\}_{t=0}^{\infty}$.

Since productivity shocks are uninsurable, households can only trade a one-period risk-free asset to self-insure, subject to the non-borrowing constraint given by equation (3). Therefore, the solution to this problem can be represented through the optimal value function $V(a_t, e_t)$, which depends on the level of assets chosen and the productivity of each household e_t. This value function is the unique solution to the following Bellman equation:

$$V(a_t, e_t) = \max_{a_{t+1}} \left\{U(c_t) + \beta E_{(e_{t+1}|e_t)}\left[V(a_{t+1}, e_{t+1})\right]\right\} \tag{4}$$

Subject to:

$$c_t + a_{t+1} = [1 + (1 - \tau_k)r_t]a_t + (1 - \tau_{\bar{n}}(\bar{e_t}))\omega_t e_t \bar{n} \tag{5}$$

$$a_{t+1} \geq 0 \tag{6}$$

The solution to equation (4) (which is discussed in more detail in Appendix, Section A1) returns the well-known Euler equation:

$$\frac{\partial U(c_t)}{\partial c_t} \geq \beta E_{(e_{t+1}|e_t)}\left[(1 + (1 - \tau_k)r_{t+1})\frac{\partial U(c_{t+1})}{\partial c_{t+1}}\right] \tag{7}$$

Moreover, the assumed functional form of $U(\cdot)$ is CRRA, i.e., $U(c_t) = \frac{c_t^{1-\gamma}}{1-\gamma}, \quad \gamma > 0$

2.2 Aggregate variables

Let us define the evolution of the distribution of agents over assets and income-productivity levels $\mu(a_t, e_t)$, where:

[5] This assumption follows Domeiji & Heathcote (2004) and implies that the poorest households are not able to smooth their consumption when they face changes in their income. Moreover, this implies that households can only save through private capital assets and government bonds.

$$\mu(\bar{a}_{t+1}, \bar{e}_{t+1}) = \sum_{a_{t+1} \in A_{t+1}} \sum_{e_t \in E_t} \Pi_p(\bar{e}_{t+1}|e_t) \cdot \mathbb{I}_{\{a_{t+1}(a_t, e_t) = \bar{a}_{t+1}\}} \cdot \mu(a_t, e_t) \quad (8)$$

With:

$$\sum_{a_t \in A_t} \sum_{e_t \in E_t} \mu(a_t, e_t) = 1 \quad \text{(9a)}$$

$$\sum_{e_{t+1} \in E_{t+1}} P(e_{t+1} \mid e_t) = 1 \quad \text{(9b)}$$

Where $P(e_t) \in \mathbb{R}^l$ with $P(e_{t+1}|e_t) \geq 0,\ \forall e^l_{t+1} \in \{1, \ldots, l\}$, represents the probability vector for each e_t of the transition matrix $\Pi_p(\bar{e}_{t+1}|e_t)$. The term $I_{\{a_{t+1}(a_t, e_t) = \bar{a}_{t+1}\}}$ represents a distribution matrix over optimal saving policies that vary depending on the current productivity level e_t and the current individual asset stock a_t. Moreover, since $\Pi_p(\bar{e}_{t+1}|e_t)$ follows a Markov process such that:

$$P(e_{t+1}) = P(e_t) \cdot \Pi_p(\bar{e}_{t+1} \mid e_t) \quad (10)$$

Then $\{P(e_t)\}_{t=0}^{\infty}$ converges to a unique limit P^* for any initial distribution $P(e_0)$.

Given the convergence of $P(e_t)$ to P^*, the aggregate effective labor supply will also converge to a constant value given by: $\sum_{i=1}^{l} p_i^* e_i \bar{n}$, from which a normalization is imposed such that: $\sum_{i=1}^{l} p_i^* e_i = 1$, so the aggregate labor supply is equal to a constant value over time $\bar{n}$.

Now, given equation (8), the aggregate level of consumption and asset holdings during period t would be, respectively:

$$C_t = \sum_{a_t \in A_t,\, e_t \in E_t} c(a_t, e_t) \cdot \mu(a_t, e_t) \quad (11)$$

$$A_{t+1} = \sum_{a_t \in A_t,\, e_t \in E_t} a(a_t, e_t) \cdot \mu(a_t, e_t) \quad (12)$$

2.3 Production

Aggregate output is produced by an identical unit mass of firms in a competitive market according to a Cobb–Douglas production function, which at an aggregate level can be represented by the following maximization problem:

$$\max_{K_t} \Gamma_t = \max_{K_t} \left[p_t Y_t - (r_t + \delta) K_t - \omega_t \bar{n}\right] \tag{13}$$

for all $t = 0, 1, 2, \ldots$, subject to:

$$Y_t = K_t^{\alpha}\, \bar{n}^{\,1-\alpha} \tag{14}$$

where p_t is the price of output at time t (normalized to one), K_t is the aggregate stock of capital, $\bar{n}$ is the constant-over-time aggregate supply of labor, $\alpha \in (0, 1)$ is the share of capital in the production set, and $\delta \in [0, 1]$ is the depreciation rate of capital. Moreover, this aggregate output can be used for private consumption C_t, government consumption G_t, and investment into future capital I_t, as follows:

$$Y_t = C_t + I_t + G_t = C_t + (\Delta K_{t,t+1} + \delta K_t) + G_t \tag{15}$$

Since firms are in a perfectly competitive market for the produced good and the factors of production, and in the absence of any aggregate productivity shock, optimal prices in the factors markets at time t are given by:

$$r_t = \alpha \left(\frac{\bar{n}}{K_t}\right)^{1-\alpha} - \delta \quad \text{(16a)} \qquad \wedge \qquad \omega_t = (1-\alpha)\left(\frac{K_t}{\bar{n}}\right)^{\alpha} \quad \text{(16b)}$$

2.4 Government

Government for every period t in this economy collects taxes τ_c, τ_k and $\tau_{\bar{n}}(e_t)$ over consumption, returns on assets, and labor income, respectively; issues debt B_{t+1} which is a constant proportion of the aggregate output; pays debt from B_t at a competitive after-tax interest rate $(1-\tau_k)r_t$; and consumes part of the aggregate output G_t which depends on the dynamic of the following budget constraint[6]:

$$B_{t+1} + \tau_k r_t A_t + \omega_t \bar{n} \sum_{e_{t+1} \in E_{t+1}} P(e_{t+1} \mid e_t)\, \tau_{\bar{n}}(e_t) = [1 + r_t] B_t + G_t \tag{17}$$

Since we want to evaluate the effects of a change from linear taxation to progressive taxation on labor income, $\tau_{\bar{n}}(e_t)$ will vary depending on the

[6] Notice that, in this economy Government makes no transfer to households. Also, Government's consumption varies over time, so possible ways of increasing tax collection without affecting Government expenditure are analyzed in the experiments.

household's productivity type; therefore, the aggregate labor income tax levy will depend on the income distribution of agents.

2.4.1 The labor tax function

The labor tax function $\tau_{\bar{n}}(e_t)$ is such that, the government's levy from this type of tax must be equal for all different schemes of taxation considered[7], this is:

$$\tau_{\bar{n}}(e_t) = \begin{cases} \tau_{\bar{n}} \quad \forall e^l \in \{1, \ldots, l\}, & \text{when linear taxation} \\ h(e_i) \quad \text{for } i = \{1, \ldots, l\}, & \text{when progressive taxation} \end{cases} \tag{18}$$

Where,

$$\tau_{\bar{n}} = \sum_{i=1}^{l} p_i^* \, h(e_i) \quad \text{with} \quad h(e_i) \in [0,1], \forall i \in I \quad \text{and} \quad \frac{dh(e_i)}{de_i} > 0 \tag{19}$$

2.5 Equilibrium

Given the maximization problem of households and firms, the government budget constraint, and price setting in the factors markets, we define the stationary equilibrium in this economy, following a labor income tax reform, as follows:

Definition. *Given the implementation of the new government's labor on income tax rate $\tau_{\bar{n}}(e_t)$, the stationary equilibrium in this economy is given by the value function $V(a_t, e_t)$ with sequences of policies $\{c_t(a_t, e_t), a_{t+1}(a_t, e_t), \bar{n}\}_t$ and measures $\{\mu(a_t, e_t)\}_t$, the sequences for Government policies $\{\tau_c, \tau_k, B_t, G_t\}_t$, the sequence of firm policies $\{K_t\}_t$, and the sequence of prices $\{r_t, \omega_t\}_t$, such that:*

i. *Households' policies solve their maximization problem and achieve values $V(a_t, z_t)$ governed by (7).*

ii. *Firms' policies maximize their profits according to (16a) and (16b).*

[7] We employed this measure to capture as much as possible the isolated effect of the distribution of taxes (i.e., without affecting the aggregate levy of labor income taxes). Auerbach & Kotlikoff (1987*b*), Ferriere & Navarro (2022), Guvenen et al. (2014), and Heathcote et al. (2014) are authors that have proposed alternative measures when comparing between linear and progressive tax schemes.

iii. *Government's budget constraint given by (17) holds.*

iv. *Good market clears according to (14), where C_t is given by (11).*

v. *Assets markets clear according to:*

$$A_t = K_t + B_t, \quad \text{where } A_t \text{ is given by (12).}$$

vi. *The measure $\mu(a_t, e_t)$ evolves consistently with (8), (9a), and (9b); and μ^* is the fixed point for (8).*

2.6 Calibration

A period in this model corresponds to a year and the calibration target pursues to characterize the Nicaraguan economy in 2014. Table 1 summarizes all the fixed and calibrated parameters used in the model. For the good and factors markets, we set the supply of labor $\bar{n}$ equal to 1/3 according to Ferriere & Navarro (2022) and the standard literature. The share or elasticity of capital in the production function is set to 0.36 and the depreciation rate to 0.06, which are values extensively used in standard literature.

For households' preferences, the risk aversion parameter γ is set to be equal to one, so a logarithmic utility function is implied. The discount factor β depends on the productivity of every household[8] (therefore, on their income level) and is equal to 0.9797 on average, so that, the after-capital-tax interest rate target is set to equalize that 1.8% found by Largaespada Fernández & Brenes Narváez (2023). The interest rate target, together with the level of capital's share and depreciation rate, ensures a capital-to-output ratio[9] of around 4.44, which is near to the value reported by Alvarado (2021).

For the Government, proportional taxes on asset returns and consumption are set to a level of 0.15, representing the average value according to the Nicaraguan taxation law[10]. The debt-to-GDP ratio is fixed to a constant

[8] We opted for different discount factors to reflect the differences in Marginal Propensities to Consume that have been extensively discussed in the standard literature of Macroeconomic Analysis with Heterogeneous Agents. For more references, one can see Ferriere & Navarro (2022); Kopiec (2022); Krueger et al. (2013); Pikett & Saez (2003) , among others.

[9] Since $\dfrac{K_t}{Y_t} = \left(\dfrac{K_t}{\bar{n}}\right)^{1-\alpha}$ and condition (14a) holds, therefore: $\dfrac{K_t}{Y_t} = \dfrac{\alpha}{r_t + \delta}$.

[10] See Law No. 822, "Ley de Concertación Tributaria."

proportion of 55%, reflecting the average public debt level between 2007 and 2014, as reported by SECMCA (2024).

The initial progressive tax system is characterized by low-productivity agents not paying taxes, and medium and high-productivity agents paying tax rates of 20% and 30%, respectively. When the government moves to a linear taxation system, tax on labor income is restructured in a way the total revenue collected remains the same. Moreover, under the new linear tax scheme, tax rate becomes fixed and equal to 19.58% for all agents in the economy, ensuring that the overall tax burden is distributed uniformly.

2.6.1 Labor Productivity Process

Households receive every period an uninsurable and idiosyncratic productivity shock, which is the source of heterogeneity for this economy. The process employed in this model follows the proposal of Domeiji & Heathcote (2004) due to its simplicity, the consistency with empirical estimates for transition dynamics on income process, and the characteristic that it allows us to closely resemble the distribution of consumption for Nicaragua in 2014.

This process consists of a set E of three elements[11] $\{e_1, e_2, e_3\}$ following a transition matrix $\Pi_{p,3\times 3}$ such that:

$$\Pi_p = \begin{bmatrix} \Pi_{11} & 1-\Pi_{11} & 0 \\ \frac{1-\Pi_{22}}{2} & \Pi_{22} & \frac{1-\Pi_{22}}{2} \\ 0 & 1-\Pi_{33} & \Pi_{33} \end{bmatrix} \tag{20}$$

Where the probability of upgrading from e_1 to e_2 is equal to the probability of degrading from e_3 to e_2, this is: $p(e^2_{t+1} \mid e^1_t) = p(e^2_{t+1} \mid e^3_t) = 1 - \Pi_{11}$. Moreover, it is also assumed that households cannot move directly from low productivity to high productivity or vice versa, and the probability of moving from medium productivity to any other productivity level is the same. All this, so the number of parameters is reduced.

Given the assumptions above-mentioned and the previous normalization of the average productivity equal to one (i.e., $\sum_{i=1}^{l} p_i^* e_i = 1$), the number of

[11] Domeiji & Heathcote (2004) found in their study of the US economy that three elements were the smallest possible number of states able to resemble closely the overall wealth concentration and the small (but positive) fraction of wealth for the 40% poorest share of the population.

free parameters in this transition is four: Π_{11}, Π_{22}, and two of the elements in E.

To be consistent with the empirical estimates for the transition dynamic on income process in Nicaragua, we impose two restrictions for the Markov process of Π_p, these are: the persistence parameter for labor earnings and its variance[12] are equal to 0.8747 and 0.0747, respectively. These values were estimated specifically for the Nicaraguan economy by Flores Sarria (2013), who constructed a production function based on Nicaraguan data of GDP and labor force and, from such function, derived the persistence process for productivity.

The last two restrictions required to match the number of free parameters seek to resemble closely the distribution of consumption in the Nicaraguan economy for 2014[13]. The first restriction is the Gini coefficient, and the second is the aggregate consumption for the two poorest quintiles of the population. A more detailed description of the calibration procedure, so the delivered parameters of the transition process satisfy the four criteria above imposed, is provided in the Appendix, Section A2.

The comparison between our calibrated model before any reform in tax on labor income and the observed distribution of Consumption for the Nicaraguan economy in 2014 is presented in Table 2. In addition to simulating well the Gini coefficient and the aggregate consumption held by the 40% poorest fraction of the population, the calibrated model also resembles closely the aggregate fraction of consumption held by the third and fourth quintile of the population together as a whole, and the fraction held by the top 20%.

The calibration procedure in our model, in contrast to the ones in Domeiji & Heathcote (2004) and Heathcote (2005), is characterized by a loss of accuracy in resembling the level of consumption held by the top 20% in exchange for a gain of accuracy in resembling the income and wealth distribution in the Nicaraguan economy for 2014[14]. We set this target since the objective of

[12] In our model, both parameters are measured by the productivity component e_t.

[13] Following Domeiji & Heathcote (2004), the first criterion ensures a realistic distribution compared to that observed for Nicaragua, while the second criterion is designed to capture the bottom tail of the wealth distribution so one can draw conclusion of the effect of redistribution on this segment of the population.

[14] As observed in Table 2, the top 20% owns 52.5% of the total consumption in observed data, while our model estimates 46.3%. In comparison, Domeiji & Heathcote (2004) and

TABLE 1: Values of parameters calibration

Parameter	Name	Value	Target/Source
γ	Risk aversion	1.0	Standard literature
$\bar{n}$	Labor supply	1/3	Ferriere & Navarro (2022)
β	Discount factors	0.9520	
		0.9801	
		0.9980	Interest rate $r = 1.79\%$
α	Capital's share	0.36	Standard literature*
δ	Depreciation rate	0.06	Domeiji & Heathcote (2004)
τ_k	Assets income tax rate	0.15	Law No. 822, Ley de Concertación Tributaria
τ_c	Consumption tax rate	0.15	Law No. 822, Ley de Concertación Tributaria
τ_n	Labor income tax rate	[0, 0.2, 0.3]	Law No. 822, Ley de Concertación Tributaria
B_t/Y_t	General debt to GDP ratio	0.55	SECMCA (2024)
Productivity process			
ρ_e	Persistence in the productivity process	0.8747	Flores Sarria (2013)
σ_e^2	Variance in the productivity process	0.0747	Flores Sarria (2013)
e_1	High productivity	9.4930	Gini coefficients for consumption distribution of around 38% and for income distribution of around 46.2%
e_2	Medium productivity	0.6447	
e_3	Low productivity	0.2560	
Π_1	Persistence of low productivity	0.9220	
Π_2	Persistence of medium productivity	0.9929	
Π_3	Persistence of high productivity	0.9220	

Notes: * See Domeiji & Heathcote (2004); Ferriere & Navarro (2022); Trabandt & Uhlig (2011).
Source: Authors' calculations.

TABLE 2: Distributional properties of the baseline steady state

	Source	
Distribution of the consumption	Observed data for Nicaragua in 2014*	Estimation of our baseline Model
0% – 40%	0.240	0.2246
41% – 80%	0.235	0.3125
Top 20%	0.524	0.4629
Gini Index	Observed data for Nicaragua in 2014	Estimation of our baseline Model
Consumption*	0.38	0.358
Income**	0.46	0.4162
Wealth***	0.712	0.720

Source: *INIDE (2014), **World Bank, and ***World Inequality Database.

this model is to analyze the effects of a change in the scheme on as many variables as possible.

3 Results

In this section, we perform quantitative experiments to analyze the effects of a change in the current tax on income labor scheme over the aggregate variables and distribution of agents in this economy. More specifically, the performed experiments analyze the effects of a change from a progressive tax rate, where low-productivity households don't pay taxes on labor income, and medium and high-productivity households pay respective tax rates of 20% and 30%.

In the first experiment, the government decides to change the levy tax scheme to an equally proportional tax rate on labor income for all households (i.e., a change from progressivity to linearity). On the other hand, the second experiment analyzes the effect of a higher tax burden on households characterized by low-productive agents paying a tax rate of 5% and medium-productive agents paying a higher tax rate equal to 21%, ceteris paribus.

The first experiment evaluates the effectiveness of the current progressive taxation system in reducing inequality in the country. The second experiment pursues to highlight the effects of the rigidity of the current tax scheme on labor income, considering the evolution of nominal wages versus real wages. The solution method approach employed for solving the steady states and the transition dynamic for these experiments is discussed in detail in the Appendix, Section A.3.

3.1 Effects of a change to Linear Taxation

As mentioned in the previous section, the economy before any change is in its initial steady state with a progressive tax rate on labor income where low-productivity households do not pay taxes, and medium

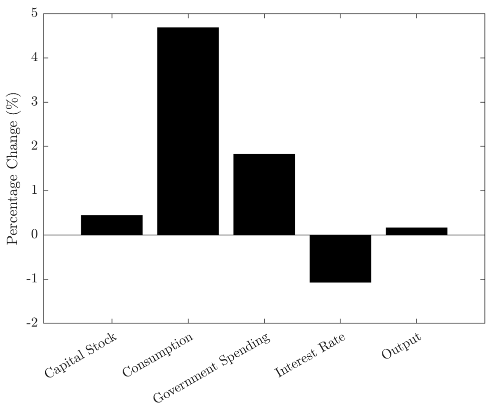
Heathcote (2005) the estimated results for the top 20% are 83.7 and 83.9, respectively, and for an observed-in-data value of 79.5 for both papers. In contrast, when comparing the distribution of income, in both papers the reported Gini coefficients are 0.21 and 0.25, respectively, while the observed-in-data value of such coefficient was 0.6. In our model estimations, the income Gini coefficient is 0.4162, which is closer to the 0.46 value reported in Nicaragua for 2014.

and high-productivity households pay respective tax rates of 20% and 30%. The change in this first experiment is such that, given the new redistribution of this taxation scheme, the aggregate levy stays the same independently. To address this fact properly, the linear tax rate equals the stationary-distribution-weighted average of the set of progressive tax rates; this is 19.58%.

Figures 1 to 5 summarize the main results from running the first experiment. In general, and in line with Auerbach & Kotlikoff (1987*b*), the results point out the existence of a tradeoff between the reduction of inequality (in this case, through the prevalent progressive taxation scheme) and the production level in the economy.

Figure 1 presents the relative changes in the main aggregate variables of the economy in response to a change in the tax scheme for labor income. As observed in the figure, the most affected variable by the linearity policy is total consumption, which, once it reaches the new equilibrium, increases by 4.7% due to the higher disposable income of more productive agents that positively affects their saving decisions.

FIGURE 1: Effect of Linear Taxation on Aggregate Variables



Source: Own elaboration.

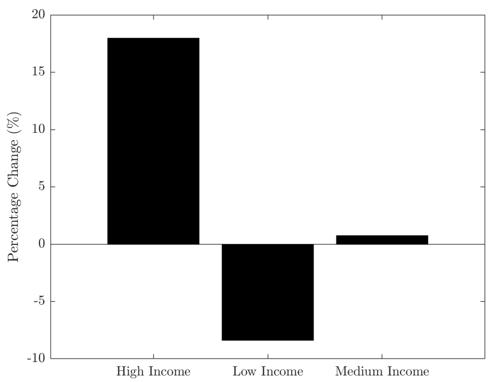
Another significantly affected variable by a change from progressivity to linearity is government spending, which increases by 1.82% potentially driven by higher revenue from taxes on consumption. For the real interest rate after taxes, this slightly decreases from 1.79% to 1.77%, which, combined with the increase in income for higher productive agents, leads to a 0.44% higher level of capital stock.

Regarding output and wages, these variables experience an equal and lower increase compared to the previously mentioned variables (around 0.15%). Moreover, the relative effect on these variables is the same due to the assumption of an inelastic labor supply and the Cobb–Douglas technology, so from now on, we focus the following discussion on output and imply that wages behave in the same way.

From Figure 1 one can highlight the difference in growth between aggregate consumption and output due to the change in the prevalent labor income tax scheme. This difference suggests that changing the current progressive tax system to a linear one is not that effective when aiming for a policy of economic growth, since the positively affected households use this extra income more on consumption rather than savings.

To analyze in more detail the effect on households' decisions, Figure 2 shows the relative changes in consumption grouped by income level. Low-income agents reduced their consumption by 8.4% due to their reduction of almost 20% in their disposable income. Medium-income agents slightly increase their consumption by 0.75%; however, high-income agents have a significantly high increase of 17.97% due to the higher disposable income they get with the linearization of the tax system.

FIGURE 2: Effect of Linear Taxation on Consumption by Income Level

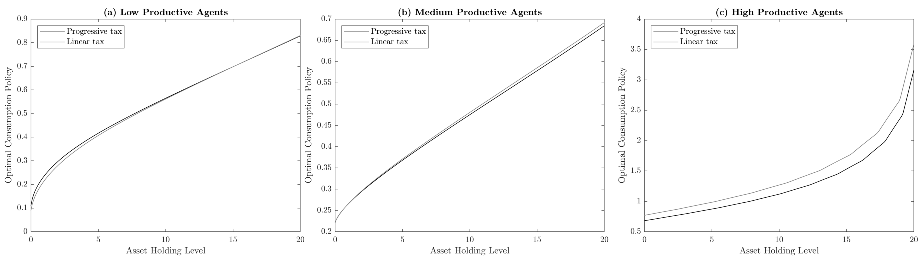


Source: Own elaboration.

The high increase in aggregate consumption is primarily driven by high-income agents, whose increased spending more than offsets the reductions observed among low-income agents. When considering disposable income, high-productive agents benefitted from the linear tax scheme, realizing approximately 14.3% more disposable income compared to the progressive scheme. Notably, their consumption rose by an even greater percentage, indicating that nearly all the additional income was allocated towards consumption rather than savings.

Figure 3 shows the optimal policy decision for consumption under both types of taxation schemes. The results are straightforward and identical to those analyzed in Figure 2; however, in Figure 3, an interesting behavior can be highlighted, this is: For low-productive agents, who experience a reduction in their disposable income, the higher effects in consumption responses are concentrated in the poorest share of the population; while for medium and high-productive, who experience an increase in their disposable income, the higher effects in consumption responses are concentrated in the richest share of the population.

FIGURE 3: Optimal Consumption Policy for Households

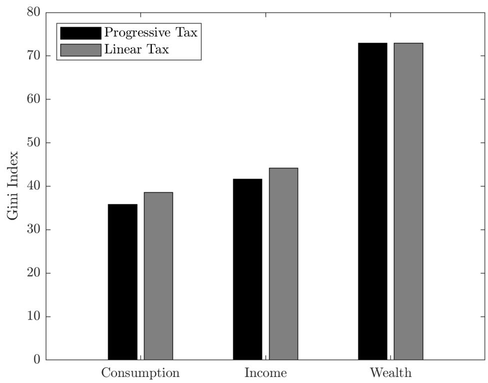


Source: Own elaboration.

This behavior across all agents in the economy reflects an exacerbation of the inequality conditions for consumption in Nicaragua when substituting the current progressive tax system for a linear scheme. In other words, given the conditions of the Nicaraguan economy, a progressive tax scheme is appropriate to reduce the differences in the consumption capacities of the population.

In addition, Figure 4 shows the effects of linear taxation on the inequality for consumption, income, and wealth. For consumption and income, the inequality conditions increased by 7.53% and 6.16%, respectively. On the other hand, the effect on wealth distribution seems to be non-significant since a decrease of 0.03% was reported.

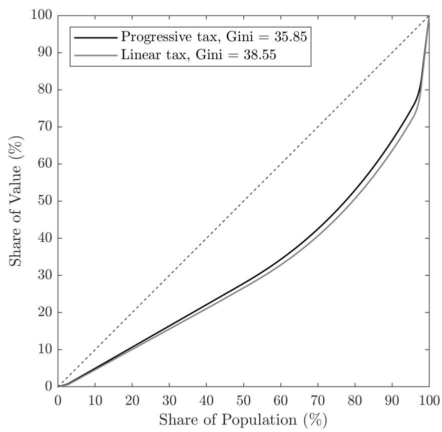
FIGURE 4: Effect of Linear Taxation on Inequality Levels



Source: Own elaboration.

Figure 5 shows the Lorenz Curves for the inequality distribution in consumption considering the two different tax schemes. From the figure, one can observe that consumption inequality effectively increases when a linear tax scheme is implemented, and around 90% of the total population gets a smaller share of the aggregate consumption.

FIGURE 5: Lorenz Curve of Inequality for Consumption



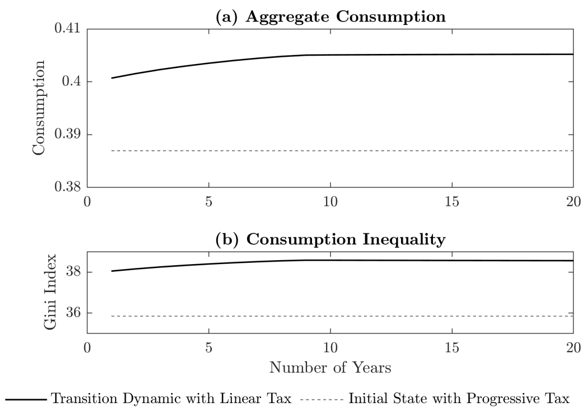
Source: Own elaboration.

3.2 Transition dynamics: a tax reform

This subsection presents the results of the transition dynamic from the initial steady state with a progressive tax scheme to the new steady state, after the government announces the unexpected change to a linear tax scheme. The results of this transition from the moment the change is announced until the economy reaches its new equilibrium are summarized in Figures 6 and 7.

Figure 6(a) shows the transition for aggregate consumption, this variable immediately jumps up from its initial steady state level of 0.387 to 0.401 due to the immediate response of a higher disposable income for medium and high-productive agents. The consumption level increases little by little as the capital stock starts gradually cumulating until it reaches a new steady state level of 0.4051 in a window of 10 years. The dynamic of consumption inequality in Figure 6(a) is similar to that of aggregate consumption and it takes 8 to 9 years to reach the new steady state.

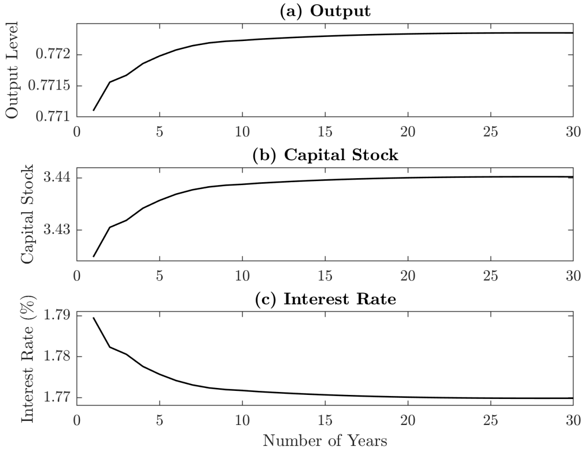
FIGURE 6: Transition Dynamic for Consumption



Source: Own elaboration.

Regarding the rest of the aggregate variables, Figure 7 presents the dynamic transition for output, capital stock, and interest rate. In contrast to the dynamic for consumption, these variables slowly increase to their new steady state levels, and they take more years to converge; nevertheless, during the first ten years, all the variables have reached at least 90% of the new steady state level.

FIGURE 7: Transition Dynamic for Aggregate Variables



Source: Own elaboration.

3.3 Effects of a Fixed Nominal Tax Scheme

The Nicaraguan progressive taxation system has been fixed in its annual nominal wage ranges since 2012. Table 3 shows how progressivity is applied according to ranges of nominal labor income, where the poorest share of the labor force pays no taxes, and the rest of the labor force pays tax rates from 15% to 30% on the income excess over the previous category.

TABLE 3: Income Tax Brackets for Annual Income

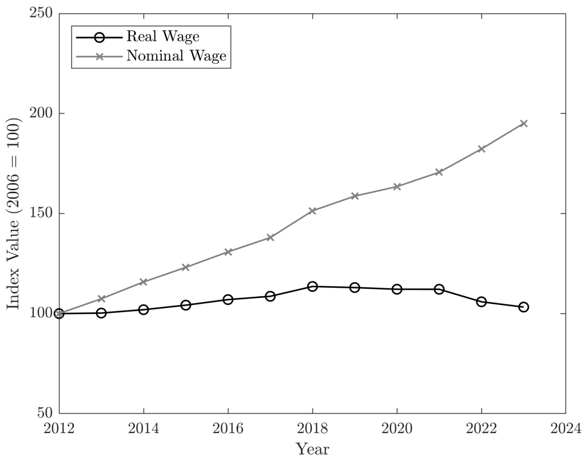
Tax Brackets		Base Fee C$	Tax Rate	Over the excess of C$
From C$	Up to C$			
0.00	100,000.00	0.00	0	0.00
100,000.01	200,000.00	0.00	15%	100,000.00
200,000.01	350,000.00	15,000.00	20%	200,000.00
350,000.01	500,000.00	45,000.00	25%	350,000.00
500,000.01	-	82,500.00	30%	500,000.00

Source: Ley de Concertación Tributaria, Nicaragua.

While this taxation system has been fixed to a nominal structure, significant issues emerge when analyzing the evolution of real wages versus nominal wages. As shown in Figure 8, nominal wages have nearly doubled since the taxation law was last updated in 2012, whereas the real wages have remained at the same level as in 2012. This discrepancy implies that low and medium-productivity agents are eventually forced to pay higher tax rates without necessarily experiencing an actual increase in their real wages.

Nominal rigidity in the taxation structure leads to a situation in which all agents in the economy, but those who are at the top category in Table 3 (high-income agents in our model), lose a share of their disposable income[15], which consequently translates into an exacerbation of the inequality conditions for income and consumption.

FIGURE 8: Evolution of Average Wages: Real versus Nominal



Source: Own elaboration.

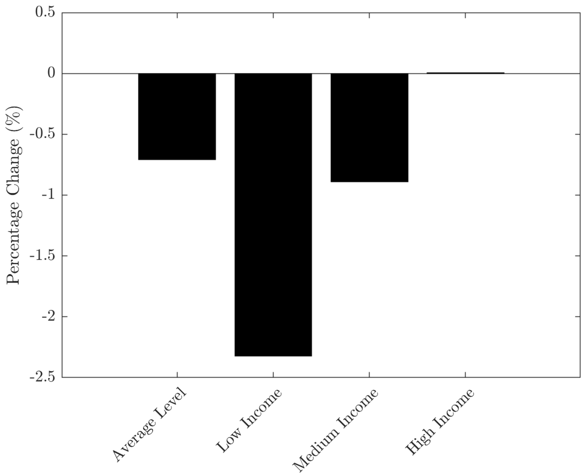
To address the effects of this issue, we conducted a second experiment in which we increased taxes for low and medium-productivity agents. This scenario mirrors the current situation in Nicaragua, where nominal tax rigidity translates into higher taxes paid by agents when they haven't experienced a real increase in their labor income. Specifically, we raise the tax rate for low-income agents from 0 to 5 percent, and for medium-income agents from 20 to 21 percent.

Figure 9 illustrates the relative change in consumption among the different types of agents, as a response to a higher tax burden resulting from invariant

[15] For instance, an average agent who used to earn in nominal terms C$ 90,000 per year, currently earns around C$ 180,000 per year and pays 15% of the excess (C$ 80,000) in taxes; however, in real terms, the wage the agent used earn in 2012 hasn't changed.

real wages. The results point out a decrease in the average consumption of 0.71%, as a significant share of the income is now allocated to pay the higher taxes. This shift is higher among low and medium-productivity workers, whose consumption decreases by 2.31% and 0.89%, respectively. On the other hand, high-productivity agents experienced no effect since they were not affected by the fixed nominal taxation structure.

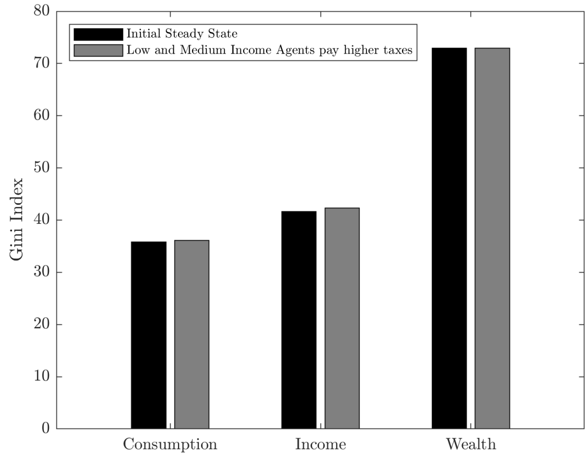
FIGURE 9: Effects on Consumption of a Higher Tax Burden (Agents with low and median income pay higher taxes)



Source: Own elaboration.

When analyzing the effects of this rigidity on inequality conditions illustrated in Figure 10, one can observe a similar increase in both the inequality for consumption and income, while the wealth distribution remains invariant. These results highlight the need for a more flexible tax system that addresses the growth disparities between nominal and real labor income, which have severe implications in terms of redistribution and might attenuate the positive effects of the current progressive taxation system on inequality.

FIGURE 10: Effects on Inequality of a Higher Tax Burden (Agents with low and median income pay higher taxes)



Source: Own elaboration.

4 Conclusions

This research examined the effects of changes in the current tax scheme on labor income in Nicaragua, a system characterized by its progressive structure. Our study aimed to provide a comprehensive evaluation of the current taxation framework's effectiveness in mitigating inequality and its broader economic implications.

Firstly, we evaluated the effectiveness of the current progressive tax scheme in reducing inequality by analyzing the effects of transitioning to a linear taxation model. Our findings revealed significant insights into how such a shift would impact different income groups and the overall economic panorama. Secondly, we assessed the implications of the fixed nature of the current taxation structure on labor income by examining the effects of increasing the tax rate for low and medium-income agents. This analysis was conducted to understand better the potential benefits and drawbacks of adjusting tax rates within the existing context.

The analysis was properly conducted using a Calibrated Dynamic Stochastic General Equilibrium Model with Heterogeneous Agents (HADSGE). This model was meticulously calibrated to accurately reflect the Nicaraguan economy's characteristics in 2014, particularly its aggregate components and distribution of consumption across all households.

The principal conclusion of our analysis is that the current tax scheme on labor income in Nicaragua is effective in reducing inequality in both consumption and income. Relative to a linear tax scheme on labor income, inequality in consumption and income would be 7.53% and 6.16% higher, respectively. Nevertheless, this structure must undergo periodic updates to account for the discrepancies between the evolution of real and nominal wages. Such updates would ensure that the system fully leverages the positive effects of progressivity on income and consumption redistribution.

Moreover, our study indicates that when the government implements an unannounced change from progressive to linear taxation, the economy's aggregate variables, such as capital stock, output, and wages, experience minimal changes. However, there is a considerable increase in aggregate consumption and its inequality levels. This tradeoff between economic efficiency and inequality conditions highlights the critical importance of maintaining progressive taxation structures, particularly in economies with characteristics similar to those of Nicaragua.

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A Appendix

A.1 Solution to the Household maximization problem

Consider the optimal value function $V(a_t, z_t)$ which is the unique solution to the following Bellman equation:

$$V(a_t, z_t) = \max_{a_{t+1}} \left\{ U(z_t - a_{t+1}) + \beta \mathbb{E}_{e_{t+1|t}} \left[V(a_{t+1}, z_{t+1}) \right] \right\} \tag{a1}$$

Subject to:

$$(1 + \tau_k) c_t + a_{t+1} = \left[1 + (1 - \tau_k) r_t \right] a_t + \left(1 - \tau_{\bar{n}}(e_t) \right) \omega_t e_t \bar{n} \tag{a2}$$

$$a_{t+1} \geq 0 \tag{a3}$$

With:

$$z_t = \left[1 + (1 - \tau_k) r_t \right] a_t + \left(1 - \tau_{\bar{n}}(e_t) \right) \omega_t e_t \bar{n} \tag{a4}$$

The First Order Conditions for a_{t+1} are such that:

$$\forall t: \quad \frac{\partial V(a_t, z_t)}{\partial a_{t+1}} = -\frac{\partial U(z_t - a_{t+1})}{\partial a_{t+1}} + \beta \mathbb{E}_{e_{t+1|t}} \left[\frac{\partial V(a_{t+1}, z_{t+1})}{\partial a_{t+1}} \right] = 0 \tag{a5}$$

Therefore:

$$\forall t: \quad \frac{\partial U(z_t - a_{t+1})}{\partial a_{t+1}} = \beta \mathbb{E}_{e_{t+1|t}} \left[\frac{\partial V(a_{t+1}, z_{t+1})}{\partial a_{t+1}} \right] \tag{a6}$$

Moreover, by the Envelop Theorem and given (a4), equation a1 is equivalent to:

$$\forall t: \quad \frac{\partial V(a_t, z_t)}{\partial a_t} = \frac{\partial U(z_t - a_{t+1})}{\partial a_t} * (1 + (1 - \tau_k) r_t) \tag{a7}$$

From (a6) and (a7), the following Euler equation for all t can be defined as:

$$\frac{\partial U(z_t - a_{t+1})}{\partial a_{t+1}} = \beta \mathbb{E}_{e_{t+1|t}} \left[(1 + (1 - \tau_k) r_{t+1}) * \frac{\partial U(z_{t+1} - a_{t+2})}{\partial a_{t+1}} \right] \tag{a8}$$

Which, given the MRS between c_t and a_{t+1} in (a2), is equivalent to:

$$\frac{\partial U(c_t)}{\partial c_t} = \beta \mathbb{E}_{e_{t+1|t}} \left[(1 + (1 - \tau_k) r_{t+1}) \frac{\partial U(c_{t+1})}{\partial c_{t+1}} \right] \tag{a9}$$

A.2 Calibration of the productivity process

This subsection is based on the proposal of Domeiji & Heathcote (2004). Consider the following AR(1) process for labor productivity:

$$\ln e_{t+1} = \rho \ln e_t + \varepsilon_t \tag{a10}$$

Where:

$$\rho = \frac{\mathrm{Cov}(\ln e_{t+1}, \ln e_t)}{\mathrm{Var}(\ln e_t)} \tag{a11.1}$$

$$\mathrm{Var}(\ln e_t) = \frac{\sigma^2}{1-\rho^2} \tag{a11.2}$$

The goal is to approximate (a10) by employing a three-state Markov chain, given the four conditions and the four free parameters defined in section 2.6.1. Given the symmetry of the matrix Π_p, the invariant vector $P^* = \{p_1, p_2, p_3\}$ possesses the following properties:

$$p_1 = p_3 \tag{a12.1}$$

$$p_2 = 1 - 2p_1 \tag{a12.2}$$

Given the two previous properties and the Markov process defined in 10, parameters Π_{11} and Π_{22} are related as follows:

$$p_1 = p_1(\Pi_{11}) + p_2\left(\frac{1-\Pi_{22}}{2}\right) \tag{a13}$$

Therefore:

$$\Pi_{22} = \frac{p_2 - 2p_1(1-\Pi_{11})}{p_2} \tag{a14}$$

From now on, let us set p_1 and e_2 to exogenous and fixed values such that, on average, they seek to resemble the two conditions regarding the consumption distribution of the Nicaraguan economy in 2014. Given the symmetry of Π_p and the fixed value of p_1, p_2 and p_3 can be easily derived; therefore, the goal is to estimate the values for Π_{11}, e_1, and e_3 so the AR(1) process defined by (a10) is conserved.

From (a10), the following equations can be derived:

$$\overline{\ln e} = \sum_i p_i \ln e_i = p_1 \ln e_1 + p_2 \ln e_2 + p_3 \ln e_3 = 0 \tag{a15.1}$$

$$\begin{aligned}\mathrm{Var}(\ln e) &= \sum_i p_i(\ln e_i - \overline{\ln e})^2 = \sum_i p_i(\ln e_i)^2 \\ &= p_1(\ln e_1)^2 + p_2(\ln e_2)^2 + p_3(\ln e_3)^2 \end{aligned} \tag{a15.2}$$

$$\begin{aligned}\mathrm{Cov}(\ln e_{t+1}, \ln e_t) &= \sum_i p_i(\ln e_{i,t} - \ln\ln e)(\ln e_{i,t+1} - \overline{\ln e}) \\ &= \sum_i p_i(\ln e_{i,t})(\ln e_{i,t+1}) \end{aligned} \tag{a15.3}$$

Now, from equation (a15.1), the value for e_3 can be estimated as follows:

$$\ln e_3 = -\frac{p_1 \ln e_1 + p_2 \ln e_2}{p_1} \tag{a16}$$

Regarding the value of e_1, let us equal the variances from (a11.2) and (a15.2) so that the following equation is derived:

$$\frac{\sigma^2}{1-\rho^2} = p_1(\ln e_1)^2 + p_2(\ln e_2)^2 + p_3(\ln e_3)^2 \tag{a17.1}$$

Which, by substituting (a16) in, delivers the following quadratic equation for $\ln e_1$:

$$2(\ln e_1)^2 + \frac{2p_2^2}{p_1}\ln e_2(\ln e_1) + \left[\frac{p_2}{p_1}\left(1+\frac{p_2}{p_1}\right)(\ln e_2)^2 - \frac{\sigma^2}{(1-\rho^2)}p_1\right] = 0 \tag{a17.2}$$

Therefore, the value of e_1 is given by the solution of (a17.2) through the relevant root for the general quadratic formula, that is:

$$\ln e_1 = \frac{-\frac{2p_2^2}{p_1}\ln e_1 - \sqrt{\left(\frac{2p_2^2}{p_1}\ln e_2\right)^2 - 4(2)\left(\frac{p_2}{p_1}\left(1+\frac{p_2}{p_1}\right)(\ln e_2)^2 - \frac{\sigma^2}{(1-\rho^2)}p_1\right)}}{2(2)} \tag{a17.3}$$

Finally, to obtain the last free parameter, let us substitute (a15.2) and (a15.3) in (a11.1), such that:

$$\rho = \frac{\sum_i p_i(\ln e_{i,t})(\ln e_{i,t+1})}{\sum_i p_i(\ln e_i)^2} = \frac{\sum_i p_i(\ln e_{i,t})\left(p(e^i_{t+1}|e^i_t)\ln e_{i,t} + \varepsilon_{t+1}\right)}{\sum_i p_i(\ln e_i)^2}$$

Equating the autocorrelation of the discrete and continuous processes for the log productivity implies that:

$$\rho = \Pi_{11} - \frac{(1-\Pi_{11})(\ln e_2)^2}{\sum_i p_i (\ln e_i)^2}$$

Where the variance can be expressed as in (a11.2), such that:

$$\rho = \Pi_{11} + \frac{(1-\rho^2)(\Pi_{11}-1)(\ln e_2)^2}{\sigma^2}$$

And therefore,

$$\Pi_{11} = \frac{\rho + \frac{(1-\rho^2)(\ln e_2)^2}{\sigma^2}}{1 + \frac{(1-\rho^2)(\ln e_2)^2}{\sigma^2}} \tag{a18}$$

A.3 Solution Algorithm

This subsection explains the algorithm employed to find the steady states of the proposed model and the transition dynamic between two different steady states.

Steady-state solution:

a. Guess the value of the aggregate capital stock K_t and –implicitly– the values for the aggregate output Y_t, the salary rate ω_t, and the interest rate r_t.

b. Solve for the households' maximization decisions considering the corresponding tax scheme. For this solution, we employed the Endogenous Grid points Method (EGM) algorithm proposed by Carroll (2006), and as in Kopiec (2023).

c. Given the consumption and saving policies, simulate the economy to generate a stationary distribution for asset holdings.

d. Set the value of the Government's total expenditure G_t, so the Government budget constraint holds given the outcomes, policy functions, and distribution in the economy.

e. Check if the clear assets' market condition holds ($A_t = K_t + B_t$).

f. If the previous condition does not hold, adjust the level of K_t and repeat the initial step until $A_t = K_t + B_t$ holds.

Transition dynamic solution:

a. Set the new value for the linear labor income tax rates according to (16). The assumption is that this change is announced before any decision from households is made in the first period.

b. Assume that, given the change in the labor income tax scheme, the economy converges to a new steady state in period T. In this step, we find the new steady state according to the *Steady-state solution* and we set the optimal values for K_t and the consumption policy as the fixed values in time T.

c. Set an initial guess for the sequence of capital stock $\{K_t\}_{t=1}^{T}$ during the whole transition. Where K_1 is the capital stock in the baseline steady state and K_T is the capital stock in the new steady state.

d. Set $c(T, a_T, e_T)$ as the optimal policy function associated with the new steady state and $\mu(1, a_1, e_1)$ as the optimal distribution of agents associated with baseline steady state.

e. Backward iteration:

   i. Use the EGM algorithm to compute $c(t, a_t, e_t)$ for all $t \in \{1, 2, \cdots, T-1\}$.

   ii. Initiate in $T-1$, where the capital stock of today is K_{T-1} and capital stock in the next period is K_T.

   iii. Estimate the expected interest rate according to K_T and the interest rate r_{T-1}, wage rate ω_{T-1} and output Y_{T-1} of today according to K_{T-1}.

   iv. Find the consumption policy in $T-1$ using the Euler equation and the EGM algorithm for r_{T-1}, ω_{T-1} and $c(T, a_T, e_T)$.

   v. Estimate the saving policy in $T-1$ associated with $c(T-1, a_{T-1}, e_{T-1})$.

   vi. Move to $T-2$, where the capital stock of today is K_{T-2} and capital stock in the next period is K_{T-1}. Repeat the steps from iii to v.

   vii. Continue moving backward until find the consumption and saving policies $(c(t, a_t, e_t))$ and $a(t, a_t, e_t)$ for all $t \in \{1, 2, ..., T-1\}$. Also, save the values for $\{r_t\}_{t=1}^{T}$, $\{\omega_t\}_{t=1}^{T}$, and $\{Y_t\}_{t=1}^{T}$.

f. Forward iteration:

i. Given the set of saving policies across the whole transition, update the distribution of agents, where $\mu(1, a_1, e_1)$ is the initial distribution for the first steady state.

ii. In $t = 1$, obtain $\mu(2, a_2, e_2)$ according to equation (6) in section 2, where $\mathbb{I}_{a_{t+1}(a_t,e_t)=\overline{a}_{t+1}}$ is given by the saving policy function $a(1, a_1, e_1)$.

iii. Repeat step ii for 2, 3, ..., $T-1$, so the whole set of $\{\mu(t, a_t, e_t)\}_{t=1}^{T}$ is updated.

iv. In this iteration, also compute the value for $\{G_t\}_{t=1}^{T}$ and the Gini coefficients in every period.

g. Convergence check:

i. $\forall t \in \{1, 2, ..., T-1\}$ compute the excess supply in the asset market for every period, this is $\{\Delta_t = A_t - K_t - B_t\}_{t=1}^{T}$.

ii. If Max $\left|\{\Delta_t\}_{t=1}^{T}\right| > \varepsilon$, where ε is a small positive number, then the equilibrium has been found. If not, the sequence for the capital stock $\{K_t\}_{t=1}^{T}$ is updated according to:

$$K_{t+1} = K_t + \Omega\Delta_t$$

where Ω is a positive small number.

iii. Take the updated guess for $\{K_t\}_{t=1}^{T}$ and repeat from step c.