Labor Supply Response to Tax Reform in a Search Model with Heterogeneous Households*

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Abstract

I develop a dynamic general equilibrium model with progressive taxation, labor market search and heterogeneous households to study the impact of tax reform on labor supply and income inequality across educational groups. Households differ in their educational level and their time preference. I study the labor supply response to tax reform along both the intensive margin (hours worked) and the extensive margins (labor force participation). The quantitative results show that: (i) a tax reform which decreases the marginal tax rate by the same magnitude of that in the Tax Reform Act of 1986 (TRA-86), has a significant impact on households' labor supply and that approximately 65 percent of the aggregate labor supply response is along the extensive margin; (ii) households' labor supply response to tax reform depends on their educational levels. Households with less education respond more significantly along both the intensive and extensive margin while the response of households with highest education is subtle. However, the income share of the highest educational group increases due to an increase in capital income after tax reform. These findings are consistent with the empirical literature studying the effects of TRA-86 on labor supply.

Keywords: Progressive Taxation, Heterogeneity, Labor Market Search, Labor Supply, Unemployment, Inequality

JEL classification: D31, E21, E24, E62, J65.

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1 Introduction

The fact that labor supply responds to tax reforms more along the extensive margin (labor force participation) than along the intensive margin (hours of work) has been well documented in the empirical labor literature[1]. Theoretical studies on the response of labor supply along the extensive margin, which include Cogan (1981), Heim and Meyer (2004), and Eissa et al. (2005), rely on the assumption that discrete labor participation decisions are explained by non-convexities created by fixed-costs of work. The standard Diamond-Mortensen-Pissarides search model can also explain discrete labor participation decisions but has not yet been used to examine labor supply response along both the intensive margin and the extensive margin.

The empirical literature also finds that tax reform has strong distributional effects, i.e., labor supply response and income response to tax reform differ across heterogeneous households. Bosworth and Burtless (1992) suggest that after the Economic Recovery Tax Act of 1981 (ERTA) and Tax Reform Act 1986 (TRA-86) the labor supply of individuals in the bottom income quintile increased significantly while the labor supply of individuals in the top income quintile increased only marginally. Lindsey (1987, 1988) finds that ERTA had a negligible impact on low-income and middle-income taxpayers while it increased the revenue response of upper-income taxpayers. This led to an increase in the share of aggregate taxes paid by upper-income taxpayers.

This paper uses the search model to explain labor supply response and income response to a tax reform. The standard deterministic neoclassical model is extended to include three additional features: labor market search, household heterogeneity, and progressive taxation. Labor market search as modeled by Diamond (1982), Mortensen (1982) and Mortensen and Pissarides (2001) is required to account for discrete participation behavior. The model assumes that labor market search is conducted in an aggregate way: all unemployed workers and vacant firms join in a single pool where unemployed workers search for jobs and vacant firms search for workers. The model also introduces two sources of household heterogeneity: the initial educational level and the time preference (subjective discount factor). Households are grouped according to their educational levels (high school dropouts, high school graduates, people with some college degree, and college graduates). Households with higher

[1] Eissa (2002) examines the labor supply response of married women to changes in the tax rate of the Tax Reform Act 86 (TRA-86). She finds that after the TRA-86 total hours worked by married women with high incomes increased by 90 hours per year on average. She also shows that the labor supply elasticity with respect to the after tax wage equals 0.8, at least half of which is explained by changes in labor force participation. Eissa and Liebman (1996) and Meyer and Rosenbaum (2001) find that the Earned Income Tax Credit (EITC), an expansion of the TRA-86, had a substantial effect on the labor force participation of single mothers but a modest impact on the hours worked.

educational levels are assumed to be more patient. In this paper tax reform is defined as a decrease in tax progressivity instituted under the TRA-86—the most notable act among all tax reforms in the 1980s which significantly decreased the US average marginal tax rate.

The quantitative results are consistent with previous empirical findings. The results show that tax reform has a significant effect on the labor supply decisions of households along both the intensive margin and the extensive margin. A 10 percent decrease in tax progressivity increases aggregate labor supply by 7 percent and approximately 65 percent of the aggregate labor supply response is along the extensive margin. This is because a decrease in tax progressivity lowers the marginal income tax rate, which encourages households to work longer hours, and it also changes the relative cost of being unemployed and employed and hence encourages the aggregate labor participation.

The results also show that households' labor supply response to tax reform depends on their educational levels. After a decrease in tax progressivity, high school dropouts, high school graduates, and people with some degree work longer hours, have a higher participation rate, and search more intensively in the labor market while college graduates work less hours, have a lower participation rate, and search less in the labor market. Among all groups, the labor supply of high school dropouts is most sensitive to a decrease in tax progressivity along both the intensive margin and the extensive margin. Furthermore, changes in earnings distribution are the direct result of changes in labor supply, and variations in income distribution mainly result from changes in income composition. The tax reform lowers the real interest rate in equilibrium which discourages people with less education (or the impatient) to save. On the contrary, savings of the college graduates (or the patient) increase due to the decrease in the marginal tax rate. As a result, a decrease in tax progressivity increases the earnings of people with low education but decreases their income and income shares. A decrease in tax progressivity decreases the earnings of college graduates but increases their incomes. The share of aggregate taxes paid by college graduates (the upper-income group) increases after the tax reform, which is consistent with findings by Lindsey (1987, 1988).

The results of the paper augment the findings of Prescott (2004) who ascribes the reason why Europeans work less than Americans to the higher marginal tax rates in Europe compared to America. However, Prescott's study focuses on examining the influence of different tax rates on hours worked per worker without taking into account households' labor force participation decisions. This paper asserts that higher marginal tax rates explain Europe's low labor force participation rate and the shorter worked hours.

The paper is related to two strands of literature on modelling discrete labor participation decisions. The first relies on the assumption of non-convexities created by work costs (Cogan (1981), Heim and Meyer (2004), and Eissa et al. (2005)). In particular, fixed costs are needed to enter the labor market, which implies that individuals choose to be unemployed if the hours of work are less than some minimum level. The second focuses on tax policies in labor search models. Shi and Wen (1999) and Domeij (2005) study optimal taxation in search models while Michaelis and Birk (2006) examine the impact of tax reform on employment and economic growth in an endogenous model with labor market search. All of these models assume a representative agent and do not examine the impact of tax reform on the labor supply and income distribution. The use of search models with heterogeneous household to examine the labor supply response to tax reform has not been well developed. This paper fills the gap in the literature by proposing a theoretical model with heterogeneous households and labor market frictions that predicts labor supply response along the intensive margin and the extensive margin.

The rest of the paper is organized as follows. Section 2 presents the model. The calibration methods are explained in section 3. The results are presented in section 4. Section 5 concludes.

2 The Model

Time is discrete. The economy includes four types of agents: households, firms, financial intermediaries (or banks), and the government. There is one consumption/investment good in the economy, which is produced by capital and labor. The goods market and the capital market are competitive while the labor market is frictional as in Diamond (1982), Mortensen (1982) and Mortensen and Pissarides (2001). Households are heterogeneous and each household contains a continuum of members—referred to as "large household"[2]. Members of any household are either employed, unemployed, or are out of the labor force. The employed members are matched with firms while the unemployed members search for jobs. Each period, by paying a flow cost, firms create job vacancies to search for workers. Successful matches between the unemployed and vacant firms are determined by a matching function proposed by Diamond (1982) and Blanchard and Diamond (1990). A representative financial intermediary collects deposits from households, owns firms, and invests in the capital market. Finally, the government collects tax incomes to finance government spending and unemployment benefits paid to

[2] This assumption will be further explained in households' problem.

the unemployed household members.

2.1 Households

Consider an economy populated by M groups of households. Let $i \in \{1, 2, ..., M\}$ be the index of group i. In any group i, there is a continuum of identical households. A household from group i is referred to as a type-i household. Any type-i household is assumed to comprise a continuum of *ex ante* identical, infinitely lived members with measure one. Then, aggregate population can be normalized to one, with group i's population share given by $\lambda_i \in (0, 1)$. This implies $\sum_{i=1}^{M} \lambda_i = 1$.

Households across different groups are heterogeneous in two dimensions: the initial educational level and the subjective discount factor. According to households' initial educational level they are divided into four groups: high school dropouts, high school graduates, people with some college degree, and college graduates. In this paper, households with higher education are assumed to be more patient compared to households with less education, which is supported by empirical studies as in Lawrance (1991) and Warner and Pleeter (2001).

Each member from a type-i household faces displacement risks regarding her/his employment status in each period. Uncertain employment status adds to the uncertainty of income and leisure of each member. As widely applied in the literature, to eliminate the impact of the uncertainty of income and leisure, each household is assumed to be large. To be specific, each household is assumed to have a continuum of members; all members within the same household pool their resources (incomes and assets) together in every period; and all members only value the household's utility instead of their own. Therefore, a household provides perfect insurance in consumption, income and leisure for its members. All the decisions regarding consumption, saving, time allocations and so on are made at the household level in a deterministic fashion[3].

2.1.1 Employment Status

Consider an arbitrary household from group i. In each time period, a member from a type-i household is either employed (a type-i worker) or non-employed (a non-worker). Denote $e_{i,t}$ and $d_{i,t} = 1 - e_{i,t}$ as the number of employed members and the number of non-employed members in a type-i household respectively. Given that the population of a type-i household is normalized to one, the variable $e_{i,t}$ can also be interpreted as the employment-population rate. Each member of a household, regardless

[3] This formulation can be found in Andolfatto (1996), Shi and Wen (1999), Chen et al. (2011a, 2011b) among others.

of its employment status, is endowed with one unit of time. Employed members allocate their time to work $l_{i,t}$ and leisure $(1 - l_{i,t})$, while non-employed members allocate their time to job searching $s_{i,t}$ and leisure $(1 - s_{i,t})$. The search intensity augmented unemployment in a type-i household—the number of unemployed members—is defined as $s_{i,t}d_{i,t}$. This description of household's employment status and time allocation is similar to Andolfatto (1996) and Chen et al. (2011a, 2011b).

At the beginning of time $t \geq 0$, the number of employed members $e_{i,t}$ is predetermined in the previous time period. Among the currently employed a fraction $\phi_i \in (0, 1)$ will be displaced at the end of time t because of an exogenous job separation shock; among the unemployed members a fraction $\mu_t \in (0, 1)$, where μ_t is the job finding rate, will be employed in the next period. Therefore, the number of the non-employed of a type-i household who succeed in finding a new job is given by $s_{i,t}d_{i,t}\mu_t$. The job finding rate μ_t, which is endogenously determined in equilibrium, is taken as given when households make decisions. Therefore, the number of employed members of a type-i household at time $t + 1$ is given by

$$e_{i,t+1} = (1 - \phi_i)\, e_{i,t} + s_{i,t}d_{i,t}\mu_t. \tag{1}$$

In each time period t, group i's unemployment rate $u_{i,t}$ is defined as

$$u_{i,t} = s_{i,t}\, (1 - e_{i,t}) \,/\, [e_{i,t} + (1 - e_{i,t})\, s_{i,t}]\,.$$

where $e_{i,t} + (1 - e_{i,t})\, s_{i,t}$ are the number of members participating in the labor force in a type-i household (labor force participation of a type-i household).

2.1.2 Budget Constraint

In each period, a type-i household has three sources of income. The first source is the labor income $\eta_i w_{i,t} l_{i,t} e_{i,t}$ where $w_{i,t}$, η_i and $l_{i,t}$ denote the wage rate, the labor productivity, and hours worked of a type-i worker respectively. The productivity of the worker is predetermined by his/her initial educational level. The product $\eta_i l_{i,t}$ is the level of effective labor. The wage rate for raw labor $l_{i,t}$ is $\eta_i w_{i,t}$. The second source of income is unemployment benefits. The non-employed members get unemployment benefits from the government, which is a fraction ρ of their labor income[4]. The third source of income is interest from assets $r_t a_{i,t}$ where $a_{i,t}$ and r_t denote asset holdings by a type-i

[4] In this paper, I assume that all non-workers get compensations from the government. In fact, only a portion of non-workers are covered by unemployment benefits in U.S. See Anderson and Meyer (1997) and Blank and Card (1991).

household and the real interest rate at time t respectively. Let $y_{i,t}$ denote the total income of a type-i household at time t. Then, $y_{i,t}$ is equal to

$$y_{i,t} \equiv \eta_i w_{i,t} l_{i,t} \left[e_{i,t} + \rho \left(1 - e_{i,t}\right)\right] + r_t a_{i,t}.$$

Household incomes are subject to a progressive tax. Denote $\tau\left(\bar{y}_{i,t}\right)$ as the tax rate of a type i household where $\bar{y}_{i,t}$ is household i's relative income, i.e., the ratio of household i's income with respect to aggregate income. In particular, the relative income $\bar{y}_{i,t}$ is equal to $y_{i,t}/y_t$ where $y_t = \sum_{i=1}^{M} \lambda_i y_{i,t}$ is the aggregate income. Therefore, the tax rate of a given household depends on its position in the income distribution. The total amount of income tax paid by a type-i household $T\left(y_{i,t}\right)$ is equal to $\tau\left(\bar{y}_{i,t}\right) y_{i,t}$. Following Guo and Lansing (1998) and Li and Sarte (2004)[5], the tax rate is captured by the relative income [6] and further assumed to be of the form

$$\tau\left(\bar{y}_{i,t}\right) = \sigma \left(\frac{y_{i,t}}{y_t}\right)^{\varrho}, \quad with \;\; 0 \leq \sigma < 1, \;\; \varrho > 0.$$

where σ and ϱ determine the level and the slope of the tax schedule, respectively.

Unlike a flat tax system—a system in which the average tax rate equals the marginal tax rate—a progressive tax schedule has a different average and marginal tax rates. The average tax rate (ATR) is $\tau\left(\bar{y}_{i,t}\right)$ while the marginal tax rate (MTR) is given by

$$MTR = T'\left(y_{i,t}\right) = \frac{\partial\left[\tau\left(\bar{y}_{i,t}\right) y_{i,t}\right]}{\partial y_{i,t}} = \left(1 + \varrho\right) \tau\left(\bar{y}_{i,t}\right).$$

where y_t is taken as given when a type-i household calculates his/her marginal tax rate since it is assumed that households are small compare to the aggregate population. The ratio of the marginal tax rate to the average tax rate is

$$\frac{MTR}{ATR} = \frac{T'\left(y_{i,t}\right)}{\tau\left(\bar{y}_{i,t}\right)} = 1 + \varrho.$$

Therefore, ϱ can be interpreted as the degree of tax progressivity[7]. When $\varrho = 0$, it degenerates to a flat tax case; when $\varrho > 0$, households with higher income are subject to higher tax rates.

[5] In a model without growth, Guo and Lansing (1998) use the same formulation as the tax code used here. They also mention that if there is growth in the model, the use of relative income guarantees that the tax rate $\tau\left(\bar{y}_i\right)$ is smaller than 1. In a model with growth, Li and Sarte (2004) use this formulation.

[6] Suits (1977) and Kakwani (2001) also use income levels to capture households' tax burden.

[7] See Li and Sarte (2004) for more discussion.

Let $c_{i,t}$ be the consumption of a type-i household at time t. The budget constraint of a type-i household at time t is then given by

$$c_{i,t} + a_{i,t+1} = y_{i,t} - T\left(y_{i,t}\right) + a_{i,t}. \tag{2}$$

2.1.3 The Household's Problem

In each period, households derive utility from current consumption and leisure. The period utility of a type-i household is given by

$$U\left(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t}\right) = R\left(c_{i,t}\right) + e_{i,t}H^1\left(1 - l_{i,t}\right) + \left(1 - e_{i,t}\right)H^2\left(1 - s_{i,t}\right).$$

Following Andolfatto (1996) and Chen et al. (2011a, 2011b), functions R, H^1 and H^2 are increasing and concave with respect to their augment. The utility function shows that the household values leisure from the employed members and leisure from the non-employed members differently.

The life time utility of a type-i household is $\sum_{t=0}^{\infty}\beta_i^t U\left(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t}\right)$ where β_i is the subjective discount factor for a type-i household. Given variables describing the aggregate market $\{\mu_t, r_t, w_{i,t}\}_{t=0}^{\infty}$ and government tax policy, a type-i household's problem is to choose an allocation $\mathcal{A} \equiv \{c_{i,t}, l_{i,t}, s_{i,t}, a_{i,t+1}, e_{i,t+1}\}_{t=0}^{\infty}$ to solve the following problem

$$\max_{\mathcal{A}} \left\{ \sum_{t=0}^{\infty} \beta_i^t U\left(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t}\right) \right\}.$$

subject to (1) - (2), $c_{i,t} \geq 0$, $l_{i,t} \in [0, 1]$ and $s_{i,t} \in [0, 1]$, and the no-Ponzi-game condition.

The first-order conditions of a type-i household's problem with respect to $\{c_{i,t}, l_{i,t}, s_{i,t}, a_{i,t+1}, e_{i,t+1}\}$ are as follows[8]

[8] The formal derivations are available in Appendix A.

$$U_c(t) = \psi_{i,t} \quad (3)$$

$$U_l(t) + \psi_{i,t}\left[1 - T'(y_{i,t})\right]\eta_i w_{i,t}\left[e_{i,t} + \rho(1 - e_{i,t})\right] = 0. \quad (4)$$

$$U_s(t) + \zeta_{i,t} d_{i,t} \mu_t = 0. \quad (5)$$

$$\psi_{i,t} - \beta_i \psi_{i,t+1}\left\{\left[1 - T'(y_{i,t+1})\right] r_{t+1} + 1\right\} = 0. \quad (6)$$

$$\beta_i\left\{U_e(t+1) + \zeta_{i,t+1}\left(1 - \phi - s_{i,t+1}\mu_{t+1}\right) + \psi_{i,t+1}\left[1 - T'(y_{i,t+1})\right]\eta_i w_{i,t+1} l_{i,t+1}(1 - \rho)\right\} = \zeta_{i,t} \quad (7)$$

where $\zeta_{i,t}$ and $\psi_{i,t}$ are the Lagrange multipliers with respect to (1) and (2) respectively. To save space, the partial derivative of the utility function is written as $U_{x_i}(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t}) = U_{x_i}(t)$ where $x_i \in \{c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t}\}$.

Equation (3) is the necessary condition determining a household's decision on consumption. At the optimum, the left-hand side of (3) describing the marginal utility of consumption equals the right-hand side—the shadow price of the consumption good. Equation (4) is the first-order condition governing a household's choice over labor supply along the intensive margin. An additional unit of time worked decreases a household's utility by $U_l(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t})$ because of a decrease in time for leisure. However, an additional unit of time worked brings an extra amount of after-tax income $[1 - T'(y_{i,t})]\eta_i w_{i,t}[e_{i,t} + \rho(1 - e_{i,t})]$. In equilibrium, the decrease in utility due to a fall in leisure must be compensated by the benefit derived from the increase in after-tax income. (5) is the equation determining a household's search intensity. Searching for an extra unit of time would decrease the household's utility by $U_s(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t})$ because of a decrease in leisure for the non-employed. On the other hand, an unemployed member in a type-i household has a probability of $d_{i,t}\mu_t$ to find a job. The benefit from searching equals $\zeta_{i,t} d_{i,t}\mu_t$, where $\zeta_{i,t}$ measures the shadow price of being employed for a type-i worker. The costs of searching equal the benefit of searching at the optimum. Equation (6) is the inter-temporal Euler equation. If a type-i household postpones one unit of consumption today, which is invested into the asset market by the household, the marginal utility would decrease by $\psi_{i,t}$ today while the investment would bring an after-tax income $[1 - T'(y_{i,t+1})] r_{t+1} + 1$ next period. This further brings an extra amount of utility $\beta_i \psi_{i,t+1}\{[1 - T'(y_{i,t+1})] r_{t+1} + 1\}$ today. At the optimum, there is no difference between saving for tomorrow and consuming today for the household.

Equation (7) governs household i's optimal choices over employment. The right-hand side of equation (7) is the shadow price of being employed. The first term of the left-hand side measures how an extra unit of employment next period would affect current leisure: a higher employment next period requires an increase in search intensity in the current period leading to a decrease in leisure in the current period. Because of labor market frictions this cost is also adjusted by the job-finding rate μ_t. The second term in the curly brackets measure how an extra amount of employment next period would affect leisure in the next period. Furthermore, an extra amount of employment next period also decreases search intensity in the next period and brings additional income (the third term in the curly brackets).

2.2 Firms

On the supply side of the economy, there is a continuum of firms. Each firm is small in the sense that a firm has only one job[9]. Hence firms and jobs can be used interchangeably. Firms can enter or exit the goods market freely (without costs). However, after entry, firms have to pay an open vacancy cost κ to search for workers. Production happens only after a firm and a worker are matched.

At any point in time, there are two types of firms/jobs: firms with filled jobs, which mean a matched pair between a firm and a type-i worker, and firms with vacant jobs. Each period, a matched firm rents capital and produces output. After production, the matched pair separate at an exogenous probability ϕ_i. Once a firm separates with its worker, it can choose to exit the goods market or to search for another worker by posting a new vacancy. Therefore, firms with vacant jobs consist of the separated firms searching for workers and new entrant firms, which are essentially the same.

A firm matched with a type-i worker, which is referred as a type-i firm, has access to a constant-return-to-scale technology

$$Y_{i,t} \equiv f\left(k_{i,t}, l_{i,t}\right) = k_{i,t}^{\alpha}\left[\eta_i l_{i,t}\right]^{1-\alpha}, \quad with\ \alpha \in (0,1)\ and\ i \in \{1, ..., M\}.$$

where $k_{i,t}$ and α are capital inputs rented by a type-i firm and the capital share in the production function. Denote δ as the depreciation rate of physical capital. Then, the profit of a type-i firm is given by $\pi_{i,t} = Y_{i,t} - \left(r_t + \delta\right) k_{i,t} - w_{i,t}\eta_i l_{i,t}$.

Denote the value function of a type-i firm and the value function of a vacancy by $J_{i,t}$ and V_t. Then $J_{i,t}$ is

[9] The assumption of small firms has been widely used in the literature especially in search models with heterogeneous workers. See Pries (2008) and Bils et al. (2012).

$$J_{i,t} = \max_{k_{i,t}} \left\{ \pi_{i,t} + \frac{1}{1+r_t} \left[(1-\phi_i) J_{i,t+1} + \phi_i V_{t+1} \right] \right\}, \quad i \in \{1, 2, ..., M\}.$$

The firm rents capital and employs a worker to maximize its lifetime value. The match survives with probability $1 - \phi_i$, and separates with probability ϕ_i. The firm matched with a type-i worker chooses the amount of capital to rent. The labor supply $l_{i,t}$ and wage rate $w_{i,t}$ are determined by bargaining between the firm and the worker in a matched pair. The first-order condition for this problem is given by

$$r_t + \delta = f_1 (k_{i,t}, \eta_i l_{i,t}). \tag{8}$$

for all $i \in \{1, 2, ..., M\}$.

A vacant job is filled by a worker according to a random matching process. If the vacancy is matched, the matched pair begins to produce output at time $t+1$. Otherwise, the cost of posting the vacancy will be wasted. The value function of a vacancy is equal to

$$V_t = -\kappa + \frac{1}{1+r_t} \left\{ q_t \sum_{i=1}^{M} \widetilde{\lambda}_{i,t} J_{i,t+1} + (1-q_t) V_{t+1} \right\}.$$

where $\widetilde{\lambda}_{i,t}$ is the ratio of the number of unemployed in group i with respect to the total unemployment, which is equal to $\lambda_i s_{i,t} d_{i,t} / \sum_{i=1}^{M} \lambda_i s_{i,t} d_{i,t}$. The nominator $\lambda_i s_{i,t} d_{i,t}$ is the unemployment in group i while the denominator $\sum_{i=1}^{M} \lambda_i s_{i,t} d_{i,t}$ is the total search intensity augmented unemployment. The free entry condition gives $V_t = 0$.

2.3 Labor Market Matching and Wage Determination

The labor market is frictional in the sense that it is time-consuming and costly for both the unemployed workers and firms to form a match in the labor market. Given households are heterogeneous, I follow Pries (2008) and Ravenna and Walsh (2011) to assume that the matching process operates in an aggregate way—the unemployed workers, regardless of their types, and vacant firms join into a pool where the unemployed search for jobs and the vacant firms search for workers. Denote the number of unemployed workers by d_t which is equal to the sum of unemployed workers in each group $\sum_{i=1}^{M} \lambda_i s_{i,t} d_{i,t}$. Let v_t be the total number of vacancies in the labor pool. Following Diamond (1982) and Blanchard and Diamond (1990), the number of new matches between the unemployed and vacancies are determined by a constant-return-to-scale matching function

$$\mathcal{M}\left(d_t, v_t\right) = B d_t^{\xi} v_t^{1-\xi} \,. \tag{9}$$

where parameters B and $\xi \in (0,1)$ represent the matching efficiency and the elasticity of the matching function, respectively. Denote $\theta_t = d_t/v_t$ as the job market tightness. The job finding rate μ_t is equal to $\mathcal{M}\left(d_t, v_t\right)/d_t = \mathcal{M}\left(\theta_t, 1\right)/\theta_t$ and the rate at which a vacancy is filled q_t is equal to $\mathcal{M}\left(d_t, v_t\right)/v_t = \mathcal{M}\left(\theta_t, 1\right)$.

As is standard in the labor search literature, wages are determined through a Nash bargaining process, which maximizes the product of a worker's surplus and a firm's surplus from matching. Denote the value function of a type-i household by $W\left(a_{i,t}, e_{i,t}\right)$. A type-$i$ household's surplus from a successful match is equal to the marginal benefit of providing an additional worker by the household, which is equal to $W_e\left(a_{i,t}, e_{i,t}\right)$. Moreover, the surplus of a vacant job is equal to $J_{i,t} - V_t$. Then, wage $w_{i,t}$ is chosen to maximize the following equation

$$\max_{w_{i,t}} \left[\frac{W_e\left(a_{i,t}, e_{i,t}\right)}{\psi_{i,t}}\right]^{\epsilon} \left[J_{i,t} - V_t\right]^{1-\epsilon},$$

where $\epsilon \in (0,1)$ denotes the bargaining power of workers and $W_e\left(a_{i,t}, e_{i,t}\right)/\psi_{i,t}$ gives the capital value of supplying an additional worker by a type-i household.

Wages are determined by the following condition

$$\epsilon J_{i,t}\left\{\left[1 - T'\left(y_{i,t}\right)\right] - \varrho T'\left(y_{i,t}\right)\frac{\eta_i w_{i,t} l_{i,t} e_{i,t}}{y_{i,t}}\right\}(1-\rho) = (1-\epsilon)\left[\frac{W_e\left(a_{i,t}, e_{i,t}\right)}{U_c\left(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t}\right)}\right]. \tag{10}$$

The detailed derivation can be found in Appendix A.

2.4 Financial Intermediary

There is a representative, infinitely-lived, and risk-neutral financial intermediary in the economy, say a bank. Banks own physical capital and equities issued by firms. Let k_t be the quantity of physical capital owned by banks at the beginning of time t. Before production, banks rent out their physical capital k_t to firms, which brings a net return of $r_t k_t$. Equities are issued by vacant firms to finance the cost of opening a job vacancy κ. I assume only banks have access to the equity market. As a result, banks own all the equity shares issued by firms in equilibrium, i.e., banks own firms. Firms pay dividends to banks at the end of each period which is equal to all of their profits.

In each time period, banks receive capital income from capital $(1+r_t)\,k_t$, derive dividend income from equity shares $\sum_{i=1}^{M}\lambda_i e_{i,t}\pi_{i,t}$ and solicit deposits from households a_{t+1}. Banks also need to pay interests and principal to deposits from last period $(1+r_t)\,a_t$, buy equity from new entrant firms $v_t\kappa_t$, and determine how much to invest in capital next period k_{t+1}. Free entry to the financial sector implies that banks make zero profit each period. As a result, the resources constraint for the entire financial sector is

$$k_{t+1}+v_t\kappa_t+(1+r_t)\,a_t=(1+r_t)\,k_t+\sum_{i=1}^{M}\lambda_i e_{i,t}\pi_{i,t}+a_{t+1}. \tag{11}$$

where $k_t=\sum_{i=1}^{M}\lambda_i e_{i,t}k_{i,t}$ and $a_t=\sum_{i=1}^{M}\lambda_i a_{i,t}$.

2.5 The Government

The government collects taxes to finance the government spending and unemployment benefits paid to the non-employed. Each period the government keeps a balanced budget.

$$\sum_{i=1}^{M}\lambda_i T\left(y_{i,t}\right)=G_t+\sum_{i=1}^{M}\lambda_i\rho\eta_i w_{i,t}l_{i,t}\left(1-e_{i,t}\right). \tag{12}$$

Based on formulations above, the equilibrium of the model is defined as:

Definition 1 *Given the tax rule, a general equilibrium in this model economy is a sequences of individual variables* $\{c_{i,t},l_{i,t},s_{i,t},a_{i,t+1},e_{i,t+1}\}_{t=0}^{\infty}$, *a pair of prices* $\{w_{i,t},r_t\}_{t=0}^{\infty}$ *for all* $i\in\{1,..,M\}$, *a pair of matching rate* $\{q(\theta_t),\mu(\theta_t)\}_{t=0}^{\infty}$ *such that:*

1. *all households and firms optimize, i.e., (3)-(7) and (8), (10) are met;*
2. *employment evolves according to (1);*
3. *labor market matching condition (9) is met;*
4. *the government budget is balanced, i.e., (12) is met;*
5. *the financial market clears, i.e., (11) is met; the goods market clears, i.e.,*

$$c_t+G_t+v_t\kappa+k_{t+1}=Y_t+(1-\delta)\,k_t \tag{13}$$

where $c_t=\sum_{i=1}^{M}\lambda_{i,t}c_{i,t}$ *and* $Y_t=\sum_{i=1}^{M}\lambda_{i,t}e_{i,t}Y_{i,t}$.

3 Calibration

This section proceeds to calibrate the baseline model presented above. One period in the model is a quarter. Based on the data available, I partition households into four groups by educational attainment: high school dropouts, high school graduates, people with some college and college graduates. High school dropouts include the households who have not completed high school. High school graduates imply the households who have obtained a high school degree but have not started college. People with some college refer to the households who have started college but have not obtained a college degree. College graduates are the households who have obtained at least a college degree. Labor productivity of each group is determined by its initial educational level and does not change over time.

Parameter values are calibrated to match the unemployment rate and employment-population ratio from the Current Population Survey (CPS) 2010[10] and the income share of each group derived from the Survey of Consumer Finance (SCF) 2010. The reason for using both of these two separated data sets is because of the data availability. The CPS 2010 has detailed information about households' unemployment rate, mean average earnings, and employment-population ratio, while the SCF 2010 includes detailed information about households' income.

Table 1 summarizes some key statistics from the CPS 2010 and the SCF 2010. Data from CPS is collected monthly. Hence, I transform monthly data to quarterly data by taking the sample average at the quarterly interval. The first four columns present data from CPS 2010, which are unemployment rate, employment population ratio, population share and quarterly wage income respectively. The unemployment rates of each group are 14.86 percent, 10.31 percent, 9.23 percent and 5.24 percent, respectively. The employment population ratios of each group are 39.41 percent, 55.28 percent, 61.91 percent and 72.26 percent respectively. The quarterly wage incomes of each group are $5,550$, $7,830$, $9,180$ and $18,000$ dollars respectively. Generally, people with higher education experience lower unemployment rate, participate more in the labor market, and earns higher wages, which suggests that education plays an important role in determining household behavior in the labor market. The last column reports the mean annual income of each educational group, which is from SCF 2010. The income gap is large. Specifically, college graduates earn about three times more than high school

[10] Statistics from CPS 2010 are collected for the civilian non-institutional population who are 25 years and over by educational attainment. Similar to Cairo and Cajner (2011), there are two reasons for using the data of households who are older than 25 years. First, since most households have finished their studies by the age of 25 I do not need to consider the possibility that young people are unemployed because they choose to go to school. Second, empirical studies show that there are higher unemployment rates for young people of all education groups. Hence, I avoid this possibility by studying households who are older than 25 years.

dropouts. Although data from SCF is annually collected, I only match the share of income received by each group in the income distribution. Then, it doesn't matter whether it is of annual frequency or quarterly frequency.

Table 2 summarizes parameter values for the baseline model. First, parameters of the tax schedule are calculated by using the NBER TAXSIM model proposed by Feenberg and Poterba (1993). According to the NBER TAXSIM data 2010, the average marginal tax rate was 21.60 percent and the average tax rate was 10.60 percent, which imply a progressivity ratio of 2.0377, i.e., $\varrho = 1.0377$. To match the average tax rate 10.60 percent , the level parameter of the tax schedule, σ, is required to equal 0.0743. Next, I calibrate parameters of the production function for the goods. Following Andolfatto (1996) and Chen et al. (2011a, 2011b), the share of capital income to aggregate output is 0.3600, i.e., $\alpha = 0.3600$. Given that the annual capital-output ratio is equal to 3 and the quarterly capital depreciation rate δ is set to 0.0150, the quarterly real interest rate r is equal to 0.0150, which implies a yearly real interest rate of 6 percent. A quarterly depreciation rate of 0.0150 is within the range of empirical estimation.

I proceed to calibrate parameters of the labor market. Following Shimer (2005), the monthly job finding rate is 0.4500, and the elasticity of matching ξ is reported to equal 0.7200. Hence the quarterly job finding rate μ is equal to 0.8340. In line with most literature of search and matching in labor market, the bargaining power for worker ϵ is set to equal to the elasticity of the matching function, i.e, $\epsilon = 0.7200$, which makes the Hosios (1990) condition holds. Also following Shimer (2005), I normalize the market tightness θ to 1 in the steady state, which implies that the constant B in front of the matching function will be equal to 0.8340. I set the unemployment benefit ρ equal to 0.2000 which is equal to the value in Bils et al. (2012). The unemployment benefit used in this model is low compared to the one in Shimer (2005) which is equal to 0.4000. Bils et al. (2012) argue that the high unemployment benefit by Shimer (2005) reflects any benefits from unemployment, such as increased leisure or home production, while their value does not include these gains. In addition to their argument, there is another reason for my model. All the unemployed workers are assumed to be eligible for unemployment benefits in this model[11]. However, according to the estimation by Anderson and Meyer (1997), Blank and Card (1991) and Regev (2012), the fraction of unemployed who are eligible for unemployment benefits is 0.4300. Therefore, the unemployment benefit on average should be lower than the value of Shimer (2005). The job separation rate is determined as follows.

[11] This assumption does not change the simulation results but it simplifies the process to solve the model.

Given that unemployment rate is defined by $u_i = s_i (1 - e_i) / [e_i + (1 - e_i) s_i]$ and the law of motion for employment in the steady state is $\phi_i e_i = \mu (1 - e_i) s_i$, the job separation rate ϕ_i is equal to $\mu u_i / (1 - u_i)$. The unemployment rate u_i and job finding rate μ are observable from the data. Thus, the job separation rate ϕ_i can be obtained. With the value of ϕ_i the value of s_i can be obtained even though it is not directly observable.

This paragraph calibrates parameters of the household's preferences. As in Li and Sarte (2004), given parameters for the tax schedule, income distribution and equilibrium interest rate, households' subjective discount factor β_i can be derived from the Euler equation $1 = \beta_i \{[1 - (1 + \varrho) \sigma (\bar{y}_i)^{\varrho}] r + 1\}$ where the income of group i is $\bar{y}_i = y_i / \left(\Sigma_{i=1}^{M} \lambda_i y_i\right)$ which is calculated by the data from SCF 2010. Following Andolfatto (1996) and Chen et al. (2011a, 2011b) the period utility function is of the form

$$U(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t}) = \ln c_{i,t} + e_{i,t} \frac{\varpi_1 (1 - l_{i,t})^{1-\omega}}{1 - \omega} + (1 - e_{i,t}) \frac{\varpi_2 (1 - s_{i,t})^{1-\omega}}{1 - \omega}.$$

where the parameters ϖ_1 and ϖ_2 are different. Thus, the household values the leisure from the employed members and the leisure from the non-employed members differently. As in Andolfatto (1996), the individual labor supply elasticity is equal to $\left(1/\bar{l} - 1\right)/\omega$ where $\bar{l}$ is average hours worked. In line with empirical studies, on average, workers spend 30 percent of their time working and the non-employed spend 14.08 percent of their time searching. I set the parameter ω equal to 3.5000 which implies that the labor supply elasticity is 0.6667. The elasticity is within the ranges of MaCurdy (1981) and Greenwood et al. (1988). MaCurdy (1981) estimates the labor supply elasticity for males ranging from 0.1000 to almost 0.5000 while Greenwood et al. (1988) argue that the labor supply elasticity for women is equal to 1.7000. Given that the average time for working and average time for searching for jobs, parameter values of ϖ_1 and ϖ_2 can be calculated, which are equal to 1.0912 and 1.3185 respectively.

Based on variable values observed in the data and parameter values derived from the above calibration, the labor supply equation gives the earning-income ratio of each group. In addition, according to the wage determination equation, wage w_i can be calculated. If I normalize $\eta_1 = 1$, earnings of group 1 can be obtained. Using the earning-income ratio just derived, the value of y_1 can be obtained. Given the income distribution, each group's relative income with respect to group 1 can be derived. As a result, the value of labor productivity η_i is obtained. Finally, the free entry condition for firms determines the value of the opening cost for a vacancy κ, which is equal to 1.7325.

4 Results

This section reports the quantitative results of the baseline model and the tax reform. The first subsection presents the baseline model results where the tax progressivity ϱ is equal to 1.0377. The second subsection shows the results after tax reform where the tax progressivity ϱ' is equal to 0.9339.

4.1 The Baseline Model

Table 4 reports the labor market performance across educational groups. Households' labor choices are characterized by hours worked, search intensity, unemployment rate, and employment-population rate. The baseline model results match the data well. While average hours worked and average search intensity in the CPS 2010 are 0.3000 and 0.1408 respectively, average hours worked and the weighted average of search intensity[12] reported by the model are 0.2987 and 0.1408 respectively. The baseline model also derives a negative correlation between unemployment rate and education and a positive correlation between employment-population rate and education, which are consistent with the data from the U.S. Bureau of Labor Statistics Current Population Survey (CPS) 2010. The model shows that the unemployment rate varies from 0.1487 for high school dropouts to 0.0525 for college graduates while employment-population rate varies from 0.3850 for high school dropouts to 0.7193 for college graduates. In the base line model, households with less education participate less in the labor market compared to college graduates, i.e., they have lower employment-population rate, since their job separation rate is higher. If they participate more, they have to search more intensively in the labor market which is not optimal for them. Workers with less education work long hours compared to workers with higher education. This is because households with less education are subject to lower income tax rate.

Table 5 summarizes household earnings, before-tax income and income shares under the baseline parameter values. The results show that earnings, before-tax income and income shares increase with education and that there is a significant difference in earnings and income across educational groups. The baseline model predicts that the earnings of college graduates are 3.5 times the earnings of high school dropouts while data from the CPS (2010) reports a similar ratio (3.2) between the earnings of college graduates and the earnings of high school dropouts. Similarly, the income of college graduates is as 3.8 times the income of high school dropouts in the baseline model which is consistent with the

[12] The weighted average hours worked are given by $\sum e_{i,t}\lambda_{i,t}l_{i,t}/\sum e_{i,t}\lambda_{i,t}$.

ratio from CPS (2010). The predicted distributions of earnings and income in the baseline model are very close to the distributions of earnings and income from the CPS (2010). Table 6 confirms that the baseline model performs well to match the observed aggregate data.

4.2 Effects of Tax Reform

In this paper, tax reform implies a 10 percent decrease in tax progressivity. This change in the marginal tax rate is equal to the change stipulated by TRA-86. Given the baseline tax progressivity $\varrho = 1.0377$, the corresponding tax progressivity under tax reform ϱ' equals 0.9339.

Table 3 reports the average tax rates and the marginal tax rates before and after the tax reform. A 10 percent decrease in tax progressivity lowers the marginal tax rates of all household groups. It also decreases the average tax rates of all groups expect that of college graduates. The percentage change in the marginal tax rates and the average tax rates decrease are negatively related with households' educational level. After a 10 percent decrease in tax progressivity the marginal tax rate of high school dropouts decreases by 18.22 percent while that of college graduates decreases only by 3.5 percent. On the other hand, the average tax rate of high school dropouts decreases by 13.74 percent while that of college graduates increases by 1.67 percent.

4.2.1 Labor Supply Response

Labor force participation is defined as the ratio of the labor force and aggregate population. Labor force is defined as the sum of employed and non-employed workers searching for a job. However, in this paper labor force participation is measured by the employment-population ratio. This measure is used because: search intensity is not directly observable in the market while employment-population rate is directly observable; the employment-population ratio and labor force participation rate are highly (positively) correlated; more important is that both measures lead to similar results about labor supply response to tax reform.

The necessary conditions of the household problem show that a decrease in tax progressivity affects household choices in three ways: for employed workers a decrease in tax progressivity decreases the marginal tax rate, which in turn changes the relative price between work and leisure—a change in labor supply along the intensive margin; a decrease in tax progressivity changes the relative cost of being unemployed or employed—a change in labor supply along the extensive margin; and a low tax progressivity decreases the real interest rate and hence affects households' saving behavior. As a result, a decrease in tax progressivity changes the income distribution across different education groups.

The results reported in Table 4 show household choices in the labor market at the steady state after the tax reform. For high school dropouts, high school graduates and people with some college degree, a decrease in tax progressivity increases hours worked by 6.97, 6.58 and 4.65 percent respectively. The increase in hours of work for these three groups is due to the decrease in the marginal tax rate, which raises the benefit of working. Furthermore, the employment-population ratios for these three groups increase by 34.91, 9.70 and 3.59 percent respectively. The calibrated results show that search intensity increases by 71.72, 25.69 and 11.73 percent for high school dropouts, high school graduates and people with some college degree respectively. After the increase in the employment-population ratios the equation of the evolvement of employment implies that households intensify their search effort in the job market for a given job finding rate. As more people search for jobs, unemployment rates across these three groups increases by 2.69, 2.91 and 2.92 percent respectively.

On the other hand, for college graduates, a decrease in tax progressivity increases the average tax rate but decreases the marginal tax rate. The calibrated results show that for college graduates hours worked, employment-population rate and search intensity decease 3.86, 5.07 and 14.63 percent respectively while unemployment rate increases 3.05 percent. Holding all other variables constant, college graduates should choose to work longer hours and have a higher participation rate after the tax reform due to the substitute effect. However, the college graduates (or the patient) choose to save more due to a decrease in the marginal tax rate which leads a higher income after the tax reform. The quantitative results show that the income effect dominates the substitute effect. Therefore, the college graduates work shorter hours and participate less in the labor market.

The quantitative results are consistent with the empirical findings. The labor supply response to tax reform happens along both the intensive margin and the extensive margin. A comparison between the percentage change in hours worked and labor force participation shows that for high school dropouts, high school graduates and college graduates, the labor supply response to tax reform tends to be concentrated along the extensive margin. Eissa and Liebman (1996), Meyer and Rosenbaum (2001) and Blundell (2011) report similar results. Furthermore, the labor supply response to tax reform differs across household education groups.

4.2.2 Earnings and Income Responses

Table 5 shows the distribution of earnings, income and income shares across educational groups after the tax reform. The quantitative results demonstrate that earnings of high school dropouts, high school graduates and people with some college degree increase by 29.92, 14.49 and 8.10 percent respectively while earnings of college graduates decrease by 6.67 percent. On the other hand, the before-tax income of household moves in the opposite direction. The incomes of high school dropouts, high school graduates and people with some college degree decrease by 21.34, 11.68 and 6.91 percent respectively while the income of college graduates increases by 9.00 percent. Moreover, the income shares of high school dropouts, high school graduates and people with some college degree decrease by 22.51, 12.99 and 8.31 percent respectively while the income of college graduates increases by 7.37 percent.

Changes in earnings across households result from the response of household labor supply to tax reform as explained in the previous sub-section. However, the change in the distribution of income needs further explanation. As described earlier, a decrease in tax progressivity increases the hours worked and the job market participation of high school dropouts, high school graduates and people with some college degree but has an opposite impact on college graduates. A decrease in tax progressivity also raises the return from saving since a lower marginal tax rate encourages investment in capital. If the interest rate remains unchanged, households will save more after a decrease in tax progressivity. However, the interest rate falls as savings increase. The quantitative results show that after the tax reform the real interest rate in equilibrium falls from 0.0150 to 0.0148, which discourages the impatient (high school dropouts, high school graduates and people with some college degree) from saving. On the other hand, savings of the patient (college graduates) rise even after a decrease in real interest rate. This is because a decrease in tax progressivity encourages college graduates to save. As a result, the income composition of college graduates changes after the tax reform. Instead of working they choose to save more. Therefore, asset holdings shift towards college graduates. The model predication that high-income group's income responds more to the tax reform is consistent with empirical studies by Lindsey (1987, 1988) and Feldstein (1995). Lindsey (1987, 1988) finds that high-income taxpayers had significantly more income after the implementation of ERTA. Feldstein (1995) finds that after the TRA-86 the taxable income of upper income taxpayers increases substantially.

4.2.3 Aggregate Effects

Table 6 reports the aggregate variables of the CPS 2010 data, the baseline model and the tax reform model. The first column shows that after the tax reform, real interest rate decreases from 0.0150 to 0.0148. The second column shows that the job finding rate decreases from 0.8330 to 0.8070 as more people look for jobs. The third column shows that after the tax reform, aggregate hours worked increase by 7 percent and approximately 65 percent of this increase is due to an increase in the labor force participation. Hence, aggregate output (column 4) increases from 1.5739 to 1.5622.

The last two columns show that inequality in earnings decreases as the Gini coefficient of earnings falls from 0.2320 to 0.1780 while inequality in income increases as the Gini coefficient rises from 0.2630 to 0.3120[13], which is equal to a 19 percent increase. Li and Sarte (2004) find that the progressivity change associated with TRA-86 results a 20 to 24 percent increase in the Gini Coefficient of income. The prediction that income inequality rises after the tax reform is also consistent with the empirical findings by Altig and Calstrom (1999), Feenberg and Poterba (1993), and Feldstein (1995). As more income shits toward higher income group, the share of aggregate taxes paid by college graduates (the upper-income group) increases after the tax reform, which is consistent with empirical findings by Lindsey (1987, 1988).

The quantitative results also show that a decrease in tax progressivity increases aggregate hours and labor force participation. These results augment the findings of Prescott (2004) who ascribes the reason why Europeans work less than Americans to the higher marginal tax rates in Europe compared to America. Prescott uses a representative agent model without considering decisions on labor force participation to examine how different marginal tax rates affect hours worked. In this paper, both household heterogeneity and household choices about labor force participation are introduced. This paper goes further than Prescott (2004) to show that higher marginal tax rates explain Europe's low labor force participation rate in addition to the shorter hours worked in Europe compared to the U.S.

5 Conclusion

Recent empirical studies find that labor supply response to tax reform are concentrated along the extensive margin rather than the intensive margin and the labor supply response and income response

[13] The Gini coefficients for both earnings and income are low compared to the empirical results because I focus on the impact of tax reform on inequalities across different educational groups and I exclude inequalities within each educational group.

to tax reform differ across household groups. These findings emphasize the importance of labor market frictions and household heterogeneity in determining household labor supply response to tax reform. However, a model of labor supply that incorporates labor market frictions and household heterogeneity has not been fully developed. In this paper I extend the standard deterministic neoclassical model to include household heterogeneity in education, heterogeneity in subjective discount factor, labor market frictions, and progressive taxation. I also simulate the impact of changes in tax progressivity on labor supply and income distribution. The model performs well to explain the labor supply response to tax reform along the extensive margin and the intensive margin.

The quantitative results of the baseline model closely fit the data from the CPS 2010 and the SCF 2010. I also find that a decrease in tax progressivity increases both the hours worked and the labor force participation. The impact of tax progressivity on the hours worked and labor force participation is strongest for high school dropouts. The results also show that the response of labor supply to tax reform is concentrated more along the extensive margin than the intensive margin as labor force participation explains approximately 65 percent of changes in aggregate hours. Moreover, a decrease in tax progressivity decreases earnings inequality and increases income inequality, unemployment rate and aggregate output. This paper goes further than Prescott (2004), which specifies a relatively higher marginal tax rate in Europe as the primary reason that Europeans work less than Americans, to show that higher marginal tax rates explain Europe's low labor force participation rate compared to the U.S..

In future studies the model can be extended to include heterogeneity within educational groups and to include endogenous human capital decisions. In this paper I assume heterogeneity in educational levels and subjective discount factors only. I further assume that people with higher education have more patience compared to people with a lower education. However, the level of patience might be different for people within the same educational group. Accounting for this heterogeneity within educational groups might improve the performance of the model in predicting the observed Gini coefficients of income and earnings. Moreover, labor productivity in the model is predetermined by a household's initial education level. Since labor productivity improves with on-the-job learning, human capital decisions should be modeled as endogenous variables. This would provide insights into the catch-up effect of income and earnings across households.

Appendix A. Equilibrium Conditions

A.1 Household Problem

Given $\{\mu_t, q_t, r_t, w_{i,t}, \kappa\}_{t=0}^{\infty}$, a type-$i$ household chooses $\{c_{i,t}, l_{i,t}, s_{i,t}, a_{i,t+1}, e_{i,t+1}\}_{t=0}^{\infty}$ to maximize its life-time utility subject to (1) and (2). Let $\zeta_{i,t}$ and $\psi_{i,t}$ be the Lagrange multipliers corresponding to (1) and (2), respectively. Set up the Lagrangian as

$$\begin{aligned}\mathcal{L} \;=\; & \sum_{t=0}^{\infty} \beta_i^t \left\{ U\left(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t}\right) + \psi_{i,t}\left[y_{i,t} - T\left(y_{i,t}\right) + a_{i,t} - c_{i,t} - a_{i,t+1}\right] \right. \\ & \left. + \zeta_{i,t}\left[\left(1-\phi\right)e_{i,t} + s_{i,t}\mu_t\left(1-e_{i,t}\right) - e_{i,t+1}\right]\right\}.\end{aligned}$$

where $y_{i,t} \equiv \eta_i w_{i,t} l_{i,t}\left[e_{i,t} + \rho\left(1-e_{i,t}\right)s_{i,t}\right] + r_t a_{i,t}$. Given the tax code $\tau\left(\bar{y}_{i,t}\right) = \sigma\left(\frac{y_{i,t}}{y_t}\right)^{\varrho}$. Denote $\bar{y}_{i,t} = y_{i,t}/y_t$ as the ratio of household i income to average aggregate income $y_t = \sum_{i=1}^{M}\lambda_i y_{i,t}$ at time t. Therefore, $T\left(y_{i,t}\right) = \tau\left(\bar{y}_{i,t}\right)y_{i,t}$ and $T'\left(y_{i,t}\right) = \sigma\left(1+\varrho\right)\left(\frac{y_{i,t}}{y_t}\right)^{\varrho}$. The first-order conditions with respect to $\{c_{i,t}, l_{i,t}, s_{i,t}, a_{i,t+1}, e_{i,t+1}\}_{t=0}^{\infty}$ are

$$\frac{\partial \mathcal{L}}{\partial c_{i,t}} = \beta_i^t\left[U_c\left(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t}\right) - \psi_{i,t}\right] = 0. \tag{A.1}$$

$$\frac{\partial \mathcal{L}}{\partial l_{i,t}} = \beta_i^t\left\{U_l\left(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t}\right) + \psi_{i,t}\left[1 - T'\left(y_{i,t}\right)\right]\eta_i w_{i,t}\left[e_{i,t} + \rho\left(1-e_{i,t}\right)\right]\right\} = 0. \tag{A.2}$$

$$\frac{\partial \mathcal{L}}{\partial s_{i,t}} = \beta_i^t\left\{U_s\left(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t}\right) + \zeta_{i,t}d_{i,t}\mu_t\right\} = 0. \tag{A.3}$$

$$\frac{\partial \mathcal{L}}{\partial a_{i,t+1}} = \beta_i^t\left(-\psi_{i,t}\right) + \beta_i^{t+1}\psi_{i,t+1}\left\{\left[1 - T'\left(y_{i,t+1}\right)\right]r_{t+1} + 1\right\} = 0. \tag{A.4}$$

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial e_{i,t+1}} \;=\; & -\beta_i^t\,\zeta_{i,t} + \beta_i^{t+1}\left\{U_e\left(c_{i,t+1}, l_{i,t+1}, s_{i,t+1}, e_{i,t+1}\right) + \zeta_{i,t+1}\left(1 - \phi - s_{i,t+1}\mu_{t+1}\right)\right. \\ & \left. +\;\psi_{i,t+1}\left[1 - T'\left(y_{i,t+1}\right)\right]\eta_i w_{i,t+1}l_{i,t+1}\left(1-\rho\right)\right\} = 0.\end{aligned} \tag{A.5}$$

Given the utility function of the following form:

$$U\left(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t}\right) = \ln c_{i,t} + \varpi_1\frac{\left(1-l_{i,t}\right)^{1-\omega}}{1-\omega}e_{i,t} + \varpi_2\frac{\left(1-s_{i,t}\right)^{1-\omega}}{1-\omega}\left(1-e_{i,t}\right).$$

then $U_c = 1/c_{i,t}$, $U_l = -\varpi_1 (1-l_{i,t})^{-\omega} e_{i,t}$, $U_s = -\varpi_2 (1-s_{i,t})^{-\omega}(1-e_{i,t})$ and $U_e = \varpi_1 \frac{(1-l_{i,t})^{1-\omega}}{1-\omega} - \varpi_2 \frac{(1-s_{i,t})^{1-\omega}}{1-\omega}$.

Substituting (A.1) into (A.2) gives,

$$\varpi_1 (1-l_{i,t})^{-\omega} e_{i,t} = \left[1 - T'(y_{i,t})\right] \eta_i w_{i,t} \left[e_{i,t} + \rho (1-e_{i,t})\right] / c_{i,t}. \tag{A.6}$$

Note that this is the standard equation governing the labor supply of employed workers. In particular, the expression $[1 - T'(y_{i,t})] \eta_i w_{i,t}$ is the after-tax wage rate for raw labor. From (A.3), I have

$$\zeta_{i,t}\mu_t = \varpi_2 (1-s_{i,t})^{-\omega}.$$

Inserting (A.1) into (A.4) gives the standard Euler equation for consumption

$$U_c(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t}) = \beta_i \left\{\left[1 - T'(y_{i,t+1})\right] r_{t+1} + 1\right\} U_c(c_{i,t+1}, l_{i,t+1}, s_{i,t+1}, e_{i,t+1}). \tag{A.7}$$

Rewrite (A.5) as

$$\begin{aligned} \frac{\varpi_2 (1-s_{i,t})^{-\omega}}{\mu_t} &= \beta_i \left\{ \frac{\varpi_1 (1-l_{i,t+1})^{-\omega}}{1-\omega} \left[1 - \frac{\omega e_{i,t+1}(1-\rho)+\rho}{e_{i,t+1}(1-\rho)+\rho} l_{i,t+1}\right] \right. \\ &\quad \left. + \varpi_2 (1-s_{i,t+1})^{-\omega} \left[\frac{1-\phi}{\mu_{t+1}} - \frac{1}{1-\omega} + \frac{\omega}{1-\omega} s_{i,t+1}\right] \right\}. \end{aligned} \tag{A.8}$$

A.2 Firm

Given the return for capital r_t, a firm chooses its capital input according to

$$r_t = f_1(k_{i,t}, \eta_i l_{i,t}) = \alpha k_{i,t}^{\alpha-1} [\eta_i l_{i,t}]^{1-\alpha}, \quad \textit{for all } i \in \{1, 2, ..., M\}$$

A firm's value can be written as

$$J_{i,t} = \max_{k_{i,t}} \left\{ \pi_{i,t} + \frac{1}{1+r_t} \left[(1-\phi_i) J_{i,t+1} + \phi_i V_{t+1}\right] \right\}, \quad i \in \{1, 2, ..., M\}$$

where $\hat{k}_{i,t} = k_{i,t} / (\eta_i l_{i,t}) = (r_t/\alpha)^{1/(\alpha-1)}$, $\hat{Y}_{i,t} = (r_t/\alpha)^{\alpha/(\alpha-1)}$ and $\pi_{i,t} = Y_{i,t} - r_t k_{i,t} - w_{i,t}\eta_i l_{i,t}$.

A.3 Bargaining

Denote $W(a_{i,t}, e_{i,t})$ as household i's value function. Thus, by increasing an extra unit of employment, a type-i household's benefit is equal to $W_e(a_{i,t}, e_{i,t})$. According to the envelope theorem

$$\begin{aligned}\frac{W_e(a_{i,t}, e_{i,t})}{U_c(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t})} = & \left\{\left[1 - T'(y_{i,t})\right] w_{i,t}\eta_i l_{i,t} + \frac{U_e(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t})}{U_c(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t})} + \right. \\ & \left. \frac{U_s(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t})}{U_c(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t})(1 - e_{i,t})}\left(\frac{1-\phi}{\mu_t} - s_{i,t}\right)\right\}.\end{aligned}$$

where $[1 - T'(y_{i,t})] w_{i,t}$ is wage income from an extra increase in employment; the second and third terms of the above equation on the right hand side is interpreted as household's reservation wage. On the other hand, a firm, matched with a type-i worker, has a value of $J_{i,t}$ at time t.

A matched firm and household bargain over the wage $w_{i,t}$ to maximize the following value

$$\max_{w_{i,t}} \left[\frac{W_e(a_{i,t}, e_{i,t})}{U_c(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t})}\right]^{\epsilon} [J_{i,t} - V_t]^{1-\epsilon}.$$

The corresponding first order condition determines wage $w_{i,t}$

$$\epsilon J_{i,t}\left\{\left[1 - T'(y_{i,t})\right] - \varrho T'(y_{i,t})\frac{w_{i,t}\eta_i l_{i,t}\left[e_{i,t} + \rho(1 - e_{i,t})\right]}{y_{i,t}}\right\}(1-\rho) = (1-\epsilon)\left[\frac{W_e(a_{i,t}, e_{i,t})}{U_c(c_{i,t}, l_{i,t}, s_{i,t}, e_{i,t})}\right].$$

Appendix B. Computational Methods;

The numerical method for solving the model along the steady state is provided below.

Step 1: Given a specific tax code and households' subject discount factors, relative income is endogenously determined by the following equation.

$$\bar{y}_i = \left[\frac{r\beta_i + \beta_i - 1}{r\beta_i\sigma(1+\varrho)}\right]^{1/\varrho} \Rightarrow \sum_{i=1}^{M} \lambda_i \bar{y}_i = 1.$$

The sum of relative income of each group must equal to 1, which further determines the interest rate.

Step 2: Given the interest rate, I select an initial guess of the job finding rate μ_0. Then, the bundle $\{r, \mu_0\}$ is used to describe the aggregate state of the model economy.

Step 3: Given $\{r, \mu_0\}$, I can proceed to solve households' problem and firms' problem. However, it is difficult to solve these problems since $\bar{y}_i$ is the relative income of a type-i household, i.e., instead of solving individual's problem separately I have to calculate all the equations simultaneously even aggregate prices are given. To simplify the calculation process, one way to go is to guess an aggregate income y^0, from which I can derive individual's choices over hours of work l_i, employment-population ratio e_i and wage rate w_i separately.

Next, by aggregating individual variables, I can find equilibrium in asset market by examining the following equation

$$\Delta_y = v\kappa + r\sum_{i=1}^{M}\lambda_i a_i - \sum_{i=1}^{M}\lambda_i e_i\left[\left[\frac{r+\delta_k}{\alpha}\right]^{\alpha/(\alpha-1)} - w_i\right]\eta_i l_i,$$

If $\Delta_y > 0$, then asset supply is larger than asset demand, the initial guess of income y^0 is too high. I should repeat this step to find a lower y^1, and vice versa. If Δ_y is smaller than a certain tolerance level, I proceed to step 4.

Step 4: By studying the free entry condition for firms, equilibrium in the labor market can be find by using the following equation

$$\Delta_\mu = \kappa - \frac{q(\theta)}{r+\phi}\sum_{i=1}^{M}\widetilde{\lambda}_i\left[(1-\alpha)\hat{Y}_i - w_i\right]\eta_i l_i,$$

If $\Delta_\mu > 0$, it is profitable for the firm to entry. Firms create more vacancies which increases $q(\theta)$ and decrease μ. Therefore, a lower μ should be chosen and I repeat the above processes from step 2.

Step 5: If both Δ_y and Δ_μ are within a tolerance level, the equilibrium is found.

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Table 1. Earnings and unemployment rates by education (Quarterly)

Education	U-R[a]	E-P-R[b]	P-S[c]	Wage $\left(10^3\right)$	Income $\left(10^3\right)$
Dropout	0.1486	0.3941	0.1284	5.55	8.43
High school	0.1031	0.5528	0.3104	7.83	12.03
Some college	0.0923	0.6191	0.1684	9.18	14.68
College	0.0524	0.7226	0.3928	18.00	32.23

Data Source: U.S. Bureau of Labor Statistics, Current Population Survey 2010; Survey of Consumer Finance 2010.

Note: Employment status of the civilian noninstitutional population 25 years and over. *a*. unemployment rate; *b*. employment-population ratio; *c*. population share.

Table 2. Baseline Parameterization

Tax Code		
Level Parameter	σ	0.0743
Degree of Progressivity	ϱ	1.0377
Production Function for the consumption Good		
Capital Share	α	0.3600
Capital Depreciation Rate	δ	0.0150
Matching		
Coefficient	B	0.8340
Labor Searcher's Share	ξ	0.7200
Bargaining Power	ϵ	0.7200
Unemployment Insurance	ρ	0.2000
Preference		
Discount Factor	β_i	[0.9862, 0.9867, 0.9870, 0.9893]
Elasticity for Leisure	ω	3.5000
Coefficient for Leisure from Employed	ϖ_1	1.0912
Coefficient for Leisure from Non-employed	ϖ_2	1.3185
Job Separation Rate	ϕ_i	[0.1455, 0.0959, 0.0848, 0.0462]
Individual Productivity	η_i	[1.0000, 1.3084, 1.6702, 3.1597]
Costs for Opening a Vacancy	κ	1.7325

Table 3. Average and Marginal Tax Before-After Tax Reform

	Dropouts	High School	Some College	College
Baseline Model $\varrho = 1.0377$				
Average Tax Rate	0.0342	0.0495	0.0608	0.1376
Marginal Tax Rate	0.0697	0.1008	0.1240	0.2804
Tax Reform $\varrho' = 0.9339$				
Average Tax Rate	0.0295	0.0458	0.0579	0.1399
Marginal Tax Rate	0.0570	0.0886	0.1120	0.2706

Table 4. Labor Market Performance of Different Groups

	Dropouts	High School	Some College	College
Hours Worked				
Baseline Model	0.3661	0.3250	0.3245	0.2616
Tax Reform	0.3916	0.3464	0.3396	0.2515
Search Intensity				
Baseline Model	0.1135	0.1421	0.1654	0.1442
Tax Reform	0.1949	0.1786	0.1848	0.1231
Unemployment Rate				
Data	0.1486	0.1031	0.0923	0.0524
Baseline Model	0.1487	0.1032	0.0924	0.0525
Tax Reform	0.1527	0.1062	0.0951	0.0541
Empl/Pop Rate				
Data	0.3941	0.5528	0.6191	0.7226
Baseline Model	0.3850	0.5474	0.6152	0.7193
Tax Reform	0.5194	0.6005	0.6373	0.6828

Table 5. Earnings, Income Levels and Income Shares across Education Groups

	Dropouts	High School	Some College	College
Earnings				
Data	0.4175	0.5886	0.6902	1.3541
Baseline Model	0.4175	0.6143	0.8515	1.4427
Tax Reform	0.5424	0.7033	0.9205	1.3464
Before Tax Income				
Data	0.5301	0.7566	0.9233	2.0276
Baseline Model	0.5301	0.7567	0.9234	2.0278
Tax Reform	0.4170	0.6683	0.8596	2.2103
Income Share				
Data	0.0542	0.1871	0.1239	0.6347
Baseline Model	0.0542	0.1871	0.1239	0.6347
Tax Reform	0.0420	0.1628	0.1136	0.6815

Note: Variable levels are derived given that the productivity of high school dropouts equals one.

Table 6. Aggregate Variables

	I-R^d	J-F-R^e	A-H^f	Output	Gini Coefficient	
					Earnings	Income
Data	–	0.8340	0.1809	1.5379	0.2290	0.2630
Baseline Model	0.0150	0.8330	0.1809	1.5379	0.2320	0.2630
Tax Reform	0.0148	0.8070	0.1946	1.5622	0.1780	0.3120

Note: d. interest rate; e. job finding rate; f. aggregate hours.