

# Teachers and the Evolution of Aggregate Inequality

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## Abstract

Teachers account for less than 5% of the workforce but have disproportionate impacts on the achievements of future generations. This paper studies how the reward structure of teachers affects the evolution of income inequality at the aggregate level. I show that, in a dynamic environment, there is a two-way relationship between teacher quality and population-wide human capital distribution. On the one hand, the occupation selection effect on teacher quality is proportional to the dispersion of human capital. On the other hand, deteriorating teacher quality elevates the dispersion itself when teachers and parental inputs are substitutes in children's human capital production. Exploiting empirical evidence on duty-to-bargain laws, I identify the model in closed form and quantify the proposed mechanism. Counterfactual results suggest that rewarding teachers' human capital, e.g., through performance-based compensations, has large dynamic spillover effects such as reducing aggregate income inequality and boosting intergenerational mobility.

**JEL classification:** I24, J24, J31, J45

**Keywords:** teachers, human capital, inequality

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# 1. Introduction

Teachers account for less than 5% of the workforce, but they play a fundamental role in shaping students' achievements and path to upward mobility (Rivkin, Hanushek and Kain 2005, Chetty, Hendren, Kline and Saez 2014b, Card, Domnisoru and Taylor 2022). It is widely acknowledged that how teachers are compensated has profound implications not only on the equilibrium of teacher labor market but also on the next generation's outcomes (Hanushek 2011).

While recent researches have made significant progress in measuring such implications (Biasi, Fu and Stromme 2021, Lovenheim and Willén 2019, Lavy 2020, Tinicani 2021, Card, Domnisoru and Taylor 2022), two important questions remain to be answered. First, how does the reward structure of teachers affect the dynamics of inequality in non-teachers and the propagation of aggregate shocks such as the skill-biased technical changes? Second, how does the magnitude of these effects evolve over time as the children being affected grow up, join the labor market, and (some of which) become teachers themselves? Will the one-generation estimates in the current literature be a lower or upper bound in a dynamic environment? These questions are important for analyzing the long-run general equilibrium impacts of education policies as well as understanding teachers' unique role in shaping aggregate inequalities.

In this paper, I study these two questions in an overlapping-generations economy with heterogeneous agents and endogenous human capital formation. Building on the framework in Bénabou (2002), the model additionally considers occupation selection into teaching and non-teaching professions. The key insight of the model is that the selection effects of education policies depend on the dispersion of human capital in the population to begin with. Therefore, in an environment with human capital formation so that the degree of dispersion is endogenous, changes in teacher selection have large *dynamic* effects.

The mechanism is briefly described as follows: consider a scenario where decreasing rewards to human capital in the teaching profession pushes the most talented

individuals into non-teaching occupations and thus reduces teacher quality. Deteriorating teacher quality reduces human capital in the next generation, with the effects being disproportionately larger among low-income families when teacher quality and parental investments are substitutes.<sup>1</sup> As a result, the economy has lower intergenerational mobility and a greater dispersion of human capital to begin with in the next generation. Importantly, this increased human capital dispersion reinforces the selection channel and leads to further reductions in teacher quality - a vicious cycle.

To quantify the mechanism, I show that the model provides analytical characterizations of optimal individual decisions as well as the transition path of the equilibrium human capital distribution. I also prove that the key parameters, especially the ones governing the human capital production function, are uniquely identified in closed form using cross-sectional moments and estimates on how teacher compensation scheme affects teacher labor market and children's outcomes. To that end, I utilize variations in duty-to-bargain laws across states and over time to measure the effects of teacher pay compression. In particular, I find that the enactment of such laws reduce both employment and earnings dispersion among teachers, while having mildly negative effects on the level of average earnings. I also borrow the corresponding estimates on children's earnings from [Lovenheim and Willén \(2019\)](#) where the authors find that duty-to-bargain laws reduce the earnings of children affected, with the effects being larger among children with parents from disadvantaged backgrounds. As non-targeted moments, the calibrated model also predicts teacher value-added that is very close to the estimates by [Chetty, Friedman and Rockoff \(2014a\)](#).

In counterfactual analyses, I show that even though teachers account for less than 5% of the total workforce, they have disproportionate impacts on the dynamics of inequality in the aggregate economy due to their fundamental roles in human capital formation. In addition, the feedback mechanism proposed in this paper results in large amplifications of skill-biased technical changes (SBTC) along the transition

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<sup>1</sup>See [Kotera and Seshadri \(2017\)](#) and [Yum \(2023\)](#). I will also verify in this condition in the calibration results using empirical evidence from duty-to-bargain laws.

path.

In the first counterfactual experiment, I raise the returns to human capital in the teaching profession by 5% to mimic a performance-based compensation reform. The magnitude of 5% is chosen to be the same as the initial impacts that duty-to-bargain laws had on the income dispersion among teachers in the empirical findings, albeit in a different direction. I find that only two-fifth of the initial impacts on teachers' income inequality, measured in the coefficient of variations, survive in the long-run steady state. Income inequality among non-teachers, however, reduces significantly by 3%, reflecting changes in the human capital dispersion itself. Intergenerational elasticity of earnings also decreases from 0.36 to 0.27 in the long run. In other words, changing returns to human capital in the teaching profession pushes the economy along the Great Gatsby curve ([Corak 2013](#)) towards less inequality and more intergenerational mobility. I also show that the magnitude of these effects varies along the transition path, approaching the new steady-state in about two generations. As a result, static or one-generation analyses overstate the effects of performance-based compensation reforms on income inequality within teachers and understate the spillover effects on intergenerational mobility and the income inequality among non-teachers.

In the second counterfactual, I study the role of teacher selection in propagating aggregate shocks, in particular on how the “convexification” of non-teaching occupations ([Autor, Goldin and Katz 2020](#)) affect income inequalities. I find that absent changes in teacher quality, the increase in income inequality among non-teachers would be 50% smaller in the long run. This is because increasing rewards to human capital in the non-teaching profession reduces teacher quality significantly, leading to a much larger dispersion of human capital in consecutive generations.

If the government wants to mitigate the adverse effects of the skill-biased technical change (SBTC) on aggregate inequalities, how much should it raise the returns to human capital among teachers? A model-based decomposition shows that to neutralize the effects of STBC, the returns to human capital among teachers actually need

to rise *relatively more* than that in non-teaching occupations. The intuition for this interesting finding is that in addition to retaining high-quality teachers, the education system needs to address the fact that SBTC widens the gap in parental income and hence the private investments in children’s human capital formation.

## Related Literature

This paper builds on the literature that studies the determinants of inequality and intergenerational mobility. The literature has traditionally focused on factors that affect the demand for education, such as credit constraints ([Lee and Seshadri 2019](#), [Caucutt and Lochner 2020](#)), information frictions ([Hoxby and Turner 2015](#)), and neighborhood effects ([Chetty, Hendren, Kline and Saez 2014b](#), [Durlauf and Seshadri 2018](#), [Fogli and Guerrieri 2019](#)). This paper contributes to the relatively small literature studying the supply side of education ([Agostinelli, Luflade, Martellini et al. 2021](#) and [Fu, Guo, Smith and Sorensen 2022](#)) by showing that teacher market reforms could be powerful instruments that move the economy along the Great Gatsby curve toward lower inequalities and greater intergenerational mobility.

This paper is also related to the large body of literature in labor and education economics that studies the structure of teacher labor market and its implications on students. The most related papers include [Hoxby \(1996\)](#) and [Lovenheim \(2009\)](#) on teacher unions, [Bacolod \(2007\)](#) on the importance of women’s alternative employment opportunities, [Lovenheim and Willén \(2019\)](#), [Lavy \(2020\)](#), [Biasi, Fu and Stromme \(2021\)](#), and [Tincani \(2021\)](#) on collective bargaining and performance-based compensation, and [Card, Domnisoru and Taylor \(2022\)](#) on school quality and minimum teacher salary laws. In various institutional settings, the literature finds that rewarding more effective teachers raises teacher quality and result in improved children’s outcomes, especially for those with disadvantaged backgrounds. To the best of my knowledge, this is the first paper to incorporate these one-generation estimates into an overlapping-generations general equilibrium setting and uncover large dynamic spillover effects into non-teaching professions.

This paper also contributes to the literature that uses quantitative methods to study the aggregate impacts of education policies (Abbott, Gallipoli, Meghir and Violante 2019, Fuchs-Schündeln, Krueger, Ludwig and Popova 2022). A key parameter in this class of models is the elasticity of substitution between parental and public inputs in children’s human capital production. This parameter governs the crowding-out effects as well as distributive consequences of government policies. While the literature either assumes it to be infinity (Daruich 2018) or calibrate it using cross-sectional variations of education expenditures as a share of income (Kotera and Seshadri 2017), this paper proposes a new identification strategy using empirical evidence on the differential impacts of duty-to-bargain laws. The results provide additional evidence showing that the two kinds of inputs are imperfect substitutes. Relative to the literature, this paper also provides a rare case where all key parameters in the quantitative model are directly identified using empirical evidence.

Last, this paper is related to the literature that studies the aggregate impacts of reward structure in some special occupations, such as government officials (Murphy, Shleifer and Vishny 1991, Acemoglu 1995) and entrepreneurs (King and Levine 1993, Baumol 1996). This paper contributes to the literature by studying another pivotal occupation in the economy – teachers. The framework developed here could be fruitfully applied to other occupations if the same amplifying mechanism applies and the set of identifying moments are available in the data.

The rest of the paper is organized as follows. In Section 2, I present the model and discuss its key assumptions and mechanisms. In Section 3, I present the identification proof and the empirical results on how duty-to-bargain laws affect teachers and students. Section 4 contains the main results on policy counterfactuals. Section 5 discusses several robustness checks. Section 6 concludes.

## 2. Model

I study an overlapping-generations economy populated by agents that live for two periods - children and adults. Children do not make any decisions. Their human capital is formed through a production function that takes teacher quality and parental investments as inputs. Adults with different levels of human capital supply labor inelastically and select into two occupations: teachers and workers (non-teachers). After occupation selection, adult parents choose child investments that maximizes their utility from consumption and preferences on their children's human capital.

### 2.1 Occupation Selection

In the beginning of each period, adults with human capital  $h$  make occupation choice after observing idiosyncratic preference shock  $\nu$  that follows a Gumbel distribution with location parameter  $\kappa$  and scale parameter  $\theta$ . They solve the following occupation choice problem:

$$\max_{j \in \{1,2\}} \mathbb{1}_{j=1} \underbrace{(\log(wh^{\psi_1}) + \nu)}_{\text{teachers}} + \mathbb{1}_{j=2} \underbrace{\log(h^{\psi_2})}_{\text{workers}}$$

where  $w$  is the relative wage across occupations and  $\psi_j$  is the occupation-specific returns to human capital.

Assume that the underlying human capital distribution of adults  $F(h)$  follows a log-normal distribution

$$\log(h) \sim F(h) = \mathcal{N}(\mu, \sigma^2)$$

The log-normality of the human capital distribution is a condition that I will verify in the equilibrium. Because human capital is endogenously formed, the values of  $\mu$  and  $\sigma^2$  are both equilibrium objects in the steady state.

I define teacher quality  $\xi$  as the z-score of average (log) human capital of teachers

in the population, i.e.,

$$\xi \equiv \frac{\overline{\log(h_1)} - \mu}{\sigma} \quad (1)$$

where  $h_1$  denotes the human capital of individuals that choose to be teachers. Throughout the paper, I use  $\bar{x}$  to denote the average value of variable  $x$ .

## 2.2 Human Capital Formation

After the occupation selection stage, adult workers become parents and have children.<sup>2</sup> Parents solve the following maximization problem

$$\max_{c, e \geq 0} \log(c) + \beta \mathbb{E}_\epsilon \log(h')$$

subject to budget constraint

$$c + e = y = h^{\psi_2}$$

and human capital production function

$$\log(h') = A + \underbrace{\log(\epsilon)}_{\text{normal dist.}} + \underbrace{\delta_0 \xi + \delta_1 \log(e) + \delta_2 \log(e)\xi}_{\text{translog}} + \underbrace{\rho \log(h)}_{\text{residual persistence}} \quad (2)$$

where  $c$  is consumption,  $e$  is education investments,  $h'$  is children's human capital,  $A$  is a normalizing constant, and  $\epsilon$  is an idiosyncratic shock that follows log-normal distribution

$$\log(\epsilon) \sim \mathcal{N}(-\sigma_\epsilon^2/2, \sigma_\epsilon^2)$$

so that  $\mathbb{E}(\epsilon) = 1$ .

I assume that average teacher quality  $\xi$  and parental investments  $e$  interact in the human capital production function (2) in a translog fashion.<sup>3</sup> Parameter  $\delta_2$  governs

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<sup>2</sup>I assume that only workers have children for analytical tractability of the model. Including teachers' children in this stage will change the results significantly because teachers account for less than 5% of the adult population.

<sup>3</sup>One can also view the translog production function as the [Kmenta \(1967\)](#) approximation to the more commonly-used CES production function.



whether they are gross complements or substitutes. I also allow for a direct spillover effect of parents' human capital to the next generation governed by  $\rho$ .

Because teachers are heterogeneous in the model, the human capital production function (2) should be interpreted as a reduced-form way of modeling how parental inputs and the pool of teachers jointly determine children's outcome. An explicit micro-foundation of the assignment problem between heterogeneous students and teachers (e.g., [Seshadri 2000](#)) is potentially important but *not* the main focus of this paper. Beyond purchasing books and computers, the role of  $\delta_1 \log(e)$  reflects parents' efforts in matching their own children to better teachers in the economy. Likewise, the interaction term  $\delta_2 \log(e)\xi$  captures the idea that need to compete for better teachers varies as the total amount of teaching resource changes.

## 2.3 Discussions

There are several points worth noting here regarding the modeling choices on occupation selection, returns to skill, and teacher quality.

First, I have assumed that individuals differ by a one-dimensional human capital  $h$  and an idiosyncratic taste shock  $\nu$ . Human capital here summarizes a broad set of personal traits that affect productivities, including but not limited to cognitive ability, non-cognitive ability, experience, and education. An alternative modeling choice is to use a multi-dimensional human capital model à la [Roy \(1952\)](#) where individuals have comparative advantage in one of the occupations ([Borjas 2002](#), [Bacolod 2007](#)). With strong positive correlation between different abilities, the Roy-style model offers the same intuition on the selection effects. Such a model, however, requires us to model separate production functions for each dimension of human capital and the corresponding mappings to productivities across occupations. In the current analysis, I restrict to the one-dimensional case for data availability reasons, but I acknowledge that the quantitative results will be smaller if *relative to* overall earnings, skills that are more important in the teaching profession (e.g., communication and interpersonal relation skills) are less affected by changes in human capital production in-

puts.

To investigate this concern further, I collect data on the importance of five cross-functional skills by occupation from O\*NET, including complex problem solving skills, resource management skills, social skills, system skills, and technical skills. I find that for each skill, the value of teachers are all within one standard deviation of the values across other non-teaching occupations (see Table 1). Thus, I do not expect including multi-dimensional human capital will change the results significantly.

Table 1: Skill Importance by Occupation

	Teacher	Non-Teachers	
	Value	Mean	Std
Complex Problem Solving Skills	3.53	3.19	0.50
Resource Management Skills	2.40	2.39	0.66
Social Skills	3.27	2.89	0.52
System Skills	3.17	2.85	0.60
Technical Skills	1.45	1.93	0.79

*Notes:* This table displays the importance of each cross-functional skills by teachers and non-teachers in the O\*NET dataset.

Second, the two parameters  $\psi_1$  and  $\psi_2$  provide sufficient statistic of the returns to human capital in teaching and non-teaching occupations respectively. It is important to note that these parameters reflects both technological differences across occupations and also policy choices. For example,  $\psi_1$  falls when the teachers' union compresses the wage distribution through collective bargaining. Likewise,  $\psi_1$  rises when school districts decide to adopt performance-based compensations. By the same token, the “convexification” of non-teaching occupations (Autor, Goldin and Katz 2020) due to skill-biased technical changes manifests itself in the model as a rise of  $\psi_2$ .

Third, in our definition teacher quality  $\xi$  reflects the *relative* position of teachers' human capital in the population. In other words, parallel shifts in the population-

wide human capital distribution, i.e., changes in  $\mu$ , does not affect teacher quality  $\xi$ . I use this definition to emphasize the selection channel and its amplification mechanisms. Our results will be stronger if teacher quality also depends on the absolute level of teachers' human capital because there will be an additional feedback loop where teacher quality feeds back on average human capital in the population and so on.

Last, I have adopted a rather stylized model of occupation selection. To focus on the propagation mechanism through endogenous human capital formation, I have abstracted away from some important margins in the context of teacher selection and quality such as the role of risk preferences (Cortes and Pan 2018), dynamic learning (Rothstein 2015), the allocation of teachers across schools or districts (Biasi, Fu and Stromme 2021), and teacher efforts (Bold, Filmer, Martin, Molina, Stacy, Rockmore, Svensson and Wane 2017). I view these possibilities as intriguing avenues for future research.

## 2.4 Model Solution

The share of adults that becomes teachers by human capital  $h$  is given by

$$l(h) = \frac{(w\kappa h^{\psi_1 - \psi_2})^\theta}{1 + (w\kappa h^{\psi_1 - \psi_2})^\theta} \approx (w\kappa h^{\psi_1 - \psi_2})^\theta$$

where the dispersion of idiosyncratic preference shock  $\theta$  governs the elasticity of occupation choice to differences in income.

Integrating  $l(h)$  across the human capital distribution  $F(h)$ , the aggregate share of teachers  $\pi$  is

$$\pi = \int l(h) dF(h) = (w\kappa)^\theta \cdot \exp\left(\mu(\psi_1 - \psi_2)\theta + \frac{((\psi_1 - \psi_2)\sigma\theta)^2}{2}\right)$$

Using the definition in Equation (1), teacher quality  $\xi$  can be solved as

$$\xi = (\psi_1 - \psi_2) \cdot \sigma \cdot \theta \tag{3}$$

Equation (3) is important as it shows that teacher quality depends on three objects. First, the relative skill bias across sectors  $(\psi_1 - \psi_2)$  represents the selection mechanism. If the relative return to human capital between teaching and non-teaching occupation rises, teacher quality  $\xi$  improves. Second, teacher quality is proportional to the dispersion of human capital among potential teachers  $\sigma$ . This captures the idea that selection is powerful when agents become more heterogeneous. Last, teacher quality also depends on  $\theta$  which reflects the elasticity that individuals move across occupations in response to changes in valuations.

A notable property of the model, as shown in Equation 3, is that teacher quality  $\xi$  is independent of relative wage  $w$ . This seems to run in contradiction to the common idea that more generous compensation attracts higher-quality teachers. To resolve this paradox, it is worth pointing out that there are two ways to increase income for teachers in the model – one is to raise  $w$  and the other is to raise  $\psi_1$ . An increase in  $w$  leads to a *uniform shift* of the  $l(h)$  profile, resulting in higher employment share  $\pi$  but leave teacher quality  $\xi$  unchanged. An increase in  $\psi_1$ , on the other hand, leads to a *rotation* of the  $l(h)$  profile, resulting in higher teacher quality  $\xi$  and an ambiguous effect on employment share  $\pi$ .

The novel part of this framework that distinguishes it from a typical static occupation selection model is the idea that in a dynamic environment, the dispersion of human capital  $\sigma$  is an endogenous object that responds to changes in occupation selection and parental investments. In other words, changes in teacher quality lead to *dynamic effects* through endogenous  $\sigma$ . In light of this, Equation (3) also provides a decomposition formula that will be used in later analysis:

$$\underbrace{d \log(\xi)}_{\text{change in teacher quality}} = \underbrace{d \log(\psi_1 - \psi_2)}_{\text{change in selection}} + \underbrace{d \log(\sigma)}_{\text{change in h.c. dispersion}} \quad (4)$$

Now I turn to optimal individual decisions. For interior solutions of  $e$ , the optimal

investment to income ratio is

$$\frac{e}{y} = \frac{\beta(\delta_1 + \delta_2\xi)}{1 + \beta(\delta_1 + \delta_2\xi)} \approx \beta(\delta_1 + \delta_2\xi)$$

Substitute  $e$  back into the human capital production function, we have

$$\log(h') = A + \log(\epsilon) + f(\xi; \vec{\delta}) + (\rho + \psi_2(\delta_1 + \delta_2\xi)) \log(h) \quad (5)$$

where  $\vec{\delta} = \{\delta_0, \delta_1, \delta_2\}$  and

$$f(\xi; \vec{\delta}) = \delta_0\xi + (\delta_1 + \delta_2\xi) \cdot \log(\beta(\delta_1 + \delta_2\xi))$$

The dynamics of Equation (5) indicate that when  $\log(h)$  is normal,  $\log(h')$  stays normal. The transition path of human capital distribution is therefore analytically characterized:

$$\begin{cases} \mu' = A + f(\xi; \vec{\delta}) + (\rho + \psi_2(\delta_1 + \delta_2\xi)) \cdot \mu - \sigma_\epsilon^2/2 \\ (\sigma')^2 = (\rho + \psi_2(\delta_1 + \delta_2\xi))^2 \cdot \sigma^2 + \sigma_\epsilon^2 \\ \xi = (\psi_1 - \psi_2) \cdot \sigma\theta \end{cases} \quad (6)$$

The system in (6) has a close relationship to [Bénabou \(2002\)](#) which exploits the properties of the normal distribution to study the relationship between tax and education policies. The key difference here is the third equation in (6) where teacher quality  $\xi$  is an endogenous object and enters the evolution of human capital. As a result, changing  $\psi_1$  or  $\psi_2$  has dynamic implications through  $\xi$  and endogenous human capital distribution.

Equation (6) also highlights the key role that  $\delta_2$  plays in determining whether teacher quality is amplified or dampened when the dispersion of human capital  $\sigma$  is endogenous. Consider a small decrease of  $\xi$  and focus on how  $\sigma'$  changes. If  $\delta_2 < 0$ , then the intergenerational persistence  $(\rho + \psi_2(\delta_1 + \delta_2\xi))$  is higher and we have higher

$\sigma'$ . This feeds back to the determination of teacher quality in the next period and leads to further declines in  $\xi'$ . On the other hand,  $\sigma'$  will be smaller when teacher quality decreases when  $\delta_2 > 0$ . Therefore, relating back to the human capital production function in Equation (2), endogenous human capital amplifies (dampens) changes in selection if and only if teacher quality is gross substitute (complement) to parental investments.

### 3. Identification and Calibration

In this section, I carry out the calibration of the model by proving identification and finding empirical counterparts to the model's predictions.

#### 3.1 Model Identification

The objects that need to be identified include

$$\underbrace{\delta_0, \delta_1, \delta_2, A, \rho, \sigma_\epsilon^2}_{\text{h.c. technologies}}, \underbrace{\kappa, \theta, \beta}_{\text{preferences}}, \underbrace{\psi_1, \psi_2}_{\text{labor market}}, \underbrace{\xi, w, \mu, \sigma^2}_{\text{endogenous objects}}.$$

This list of variables includes both deep parameters and equilibrium objects such as  $\mu$  and  $\sigma^2$ . While some objects are endogenously determined in the equilibrium, Proposition 1 shows that they serve as key auxiliary variables that facilitates the identification.

The steady-state of the model can be summarized in the following set of equations.

As discussed in Section 2.4, the optimal occupation choice of individuals result in aggregate teacher share

$$\pi = (w\kappa)^\theta \cdot \exp\left(\frac{\mu\xi}{\sigma} + \frac{\xi^2}{2}\right) \quad (7)$$

and a formula of teacher quality

$$\xi = (\psi_1 - \psi_2) \cdot \theta \sigma. \quad (8)$$

The ratio of average income between teachers and non-teachers is

$$\frac{\bar{y}_1}{\bar{y}_2} = w \cdot \exp \left( \mu(\psi_1 - \psi_2) + \frac{\sigma^2}{2}(\psi_1 - \psi_2)(\psi_1 + \psi_2 + 2\psi_1\theta) \right). \quad (9)$$

Owing to the log-normality of the human capital distribution, income inequality within occupations is given by

$$\text{CV}(y_1) = \sigma\psi_1 \quad \text{and} \quad (10)$$

$$\text{CV}(y_2) = \sigma\psi_2. \quad (11)$$

We use coefficient of variations (CV) as the main measure of inequality in this paper because it provides analytical clarity that highlights the key mechanism of the paper. Moreover, as shown by [Bendel, Higgins, Teberg and Pyke \(1989\)](#), when the underlying distribution is log-normal, coefficient of variation and the widely-used Gini coefficient are highly and positively correlated.

Using the solution to the parent's maximization problem, education expenditure to income ratio is given by

$$\frac{e}{y} = \beta(\delta_1 + \delta_2\xi). \quad (12)$$

For children who become workers when they grow up, the intergenerational elasticity of income (IGE) is given by

$$\text{IGE} = \rho + \psi_2(\delta_1 + \delta_2\xi). \quad (13)$$

Last, utilizing the human capital dynamics in Equation (6), the steady-state mean

and variance of human capital in the population can be expressed as

$$\sigma^2 = \frac{\sigma_\epsilon^2}{1 - \text{IGE}^2} \quad \text{and} \quad (14)$$

$$\mu = \frac{A + \delta_0 \xi + (\delta_1 + \delta_2 \xi) \cdot \log\left(\frac{e}{y}\right) - \sigma_\epsilon^2/2}{1 - \text{IGE}}. \quad (15)$$

I can measure  $\overline{y_1}$ ,  $\overline{y_2}$ ,  $\text{CV}(y_1)$ ,  $\text{CV}(y_2)$ ,  $\pi$ ,  $\text{IGE}$ ,  $e/y$  in the data - more details in the calibration section. Because the unit of human capital is undetermined, I have the freedom to make one normalization. After normalizing  $\psi_2 = 1$ , I need more information because there are 14 unknowns with 9 equations.<sup>4</sup>

The key insight that allows me to identify the model in closed form is that I can gather additional information from the model's comparative statics regarding a small change in  $\psi_1$ . When the economy is in the steady state, an incremental change in  $\psi_1$  has two sets of effects that can be measured in the data.

First, Equations (16) and (17) quantify how a change in  $\psi_1$  affects individual's income in the next generation. On the one hand, Equation (16) captures the (percentage) effects on the average income of workers in the next generation  $y'$ . Note that it combines a direct effect coming from changes in teacher quality  $\xi$  and an indirect effect capturing parents' responses to changing teacher quality through endogenous investments  $e$ . On the other hand, Equation (17) expresses how the effects on children's income depend on parents' current income status  $y$ . The expression highlights that the key parameter  $\delta_2$  is identified from the differential impacts between rich and poor households.

$$\frac{\partial \log(y')}{\partial \psi_1} = \psi_2 \cdot \underbrace{\sigma\theta}_{\frac{\partial \xi}{\partial \psi_1}} \left[ \underbrace{\delta_0 + \delta_2 \log(e/y) + \psi_2 \delta_2 \mu}_{\text{direct}} + \underbrace{\beta \delta_2 \cdot \frac{\delta_1 + \delta_2 \xi}{e/y}}_{\text{indirect}} \right] \quad (16)$$

$$\frac{\partial^2 \log y'}{\partial \psi_1 \partial \log y} = \sigma\theta \cdot \psi_2 \cdot \delta_2 \quad (17)$$

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<sup>4</sup>Normalizing  $\psi_2 = 1$  is without loss of generality. It is equivalent to normalizing  $\psi_1$ ,  $\sigma_\epsilon$ , or  $A$ .



The second set of equations quantify how a change in  $\psi_1$  affect income and employment share of contemporaneous teachers, In particular, Equations (18) displays the effect on average income among teachers  $\overline{y_1}$ . Equation (19) expresses the effect on the teacher share of the labor force  $\pi$ .

$$\frac{\partial \overline{y_1}}{\partial \psi_1} = \overline{y_1} \cdot (\mu + \sigma^2(\psi_1 + \theta(2\psi_1 - \psi_2))) \quad (18)$$

$$\frac{\partial \pi}{\partial \psi_1} = \pi \cdot (\theta\mu + \sigma\theta\xi) \quad (19)$$

With these additional information, the identification proof is presented next.

**Proposition 1:** The model is identified up to the calibration of  $\rho$  if we observe  $\overline{y_1}/\overline{y_2}$ ,  $CV(y_1)$ ,  $CV(y_2)$ ,  $\pi$ , IGE,  $e/y$  and measure the left-hand-sides of Equations (16)-(19).

*Proof.* Given that  $\psi_2 = 1$ , Equation (11) identifies  $\sigma$ ; then Equation (10) identifies  $\psi_1$ ; Equation (14) identifies  $\sigma_\epsilon$ . Combining Equations (18) and (19) by substituting out  $\mu$  identifies  $\theta$ . Then, Equation (8) identifies  $\xi$ ; Equation (19) identifies  $\mu$ ; Equation (9) identifies  $w$ ; Equation (7) identifies  $\kappa$ ; Equation (17) identifies  $\delta_2$ ; Equation (13) identifies  $\delta_1$  given that I calibrated  $\rho$ ; Equation (12) identifies  $\beta$ ; and lastly Equation (15) identifies  $A$ .  $\square$

### 3.2 Empirical Evidence

I measure the left-hand-sides of Equations (16)-(19) using the variations coming from the passage of duty-to-bargain (DTB) laws across states between 1960 and 1996.

Prior to 1960, teachers' unions in the United States played little role in the negotiation of contracts between teachers and school district and collective bargaining took place in only some large, urban school districts. Beginning with Wisconsin in 1960, however, states start to pass public sector duty-to-bargain (DTB) laws, which mandated that districts have to negotiate in good faith with a union that has been elected for the purposes of collective bargaining. These laws gave considerable power to teachers' unions in the collective bargaining process, leading to a sharp rise

in teacher unionization and collectively bargained contracts.

Lovenheim and Willén (2019) examine the (differential) effects of DTB laws on the next generation’s human capital and income using individual-level data from the American Community Survey (ACS). They find that a 10-year exposure to teachers under DTB laws reduces annual earnings by 2.36% (averaging men and women). Moreover, compared with Black and Hispanic children, the negative effects are 4.9 percentage points smaller among White and Asian children, whose parents had 60% higher income after adjusting for the number of children (calculated using data from the Current Population Survey (CPS) March Supplement). Similar findings are also reported in Tincani (2021) where the authors find that tying public school teacher wages to skills and introducing minimum competency requirement for teacher reduce the achievement gap between the poorest and richest 25% of students by a third.

Complementing their findings on children’s earnings, I run additional regressions to measure Equations (18) and (19). In particular, I collect data on full-time workers from the CPS-ASEC, categorize whether individuals are teachers or not based on occupation codes, and use standard two-way fixed effects methods to examine the how duty-to-bargain laws affect employment share and teacher earnings statistics

$$Y_{\text{state,year}} = \alpha_2 \cdot \text{DTB}_{\text{state,year}} + \text{State FE} + \text{Year FE} + \varepsilon \quad (20)$$

where observations are at state-year level. The regression results are shown in Table 2.

I find that DTB laws have negative (but statistically insignificant) effects on average earnings of teachers  $\bar{y}_1$  while reducing the coefficient of variations of teacher earnings by 0.03 from a base of 0.56. In addition, DTB laws reduce teacher employment share by 0.35 percentage points from a base of 4.6%. These findings are consistent with the literature that uses the recent expiration of collective bargaining agreements in some states as a source of exogenous variation. In particular, Bi-asi, Fu and Stromme (2021) shows that introducing flexible pay scheme attracted teachers from other school districts, raised the salaries of high-quality teachers, in-

Table 2: Regression Results

	(1)	(2)	(3)
	Teacher share	CV(teacher income)	Average teacher income
DTB	-0.351** (0.110)	-0.0292* (0.0138)	-591.3 (425.4)
# Observations	1378	1364	1378

Notes: This table displays the results of regression (20). Standard errors in parentheses. \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ . Average teacher earnings is measured in year 2000 dollars.

creased teacher pay dispersion measured by the coefficient of variation, and resulted in higher teacher quality.

Overall, the regression results are consistent with the interpretation that these laws mainly affect teacher market by changing the returns to human capital  $\psi_1$ . One potential worry is that variations in employment and wages could also reflect other effects of DTB laws, such as changes in relative wages  $w$  or entry barriers  $\kappa$ . I provide a detailed discussion about how this possibility affects the identification and our results in Section 5.

To utilize these estimates, I revisit Equations (16)-(19) and rewrite them as:

$$\frac{\Delta \overline{\log(y')}}{\Delta \psi_1} = \text{CV}(y_2) \cdot \theta \left[ \delta_0 + \delta_2 \log(e/y) + \psi_2 \delta_2 \mu + \beta \delta_2 \cdot \frac{\delta_1 + \delta_2 \xi}{e/y} \right] \quad (16')$$

$$\frac{\Delta^2 \log y'}{\Delta \psi_1 \Delta \log y} = \theta \delta_2 \cdot \text{CV}(y_2) \quad (17')$$

$$\frac{\Delta \log(y_1)}{\Delta \psi_1} = \mu + \sigma^2(\psi_1 + \theta(2\psi_1 - \psi_2)) \quad (18')$$

$$\frac{\Delta \pi}{\pi \Delta \psi_1} = \theta \mu + \sigma \theta \xi \quad (19')$$

The regression results in Table 2, together with the estimates in Lovenheim and Willén (2019), inform the left-hand-sides of these equations. In addition, the magnitude of changes in  $\psi_1$  can be measured using changes in the coefficient of variations

in teachers' earnings after the DTB laws were imposed:

$$\Delta\psi_1 = \psi_1 \cdot \frac{\Delta CV(y_1)}{CV(y_1)} \quad (21)$$

This equation plays an important role as it provides a direct mapping from duty-to-bargain laws in the data to the magnitude of  $\Delta\psi_1$  in the model.

### 3.3 Calibration Results

I calibrate  $\rho = 0.6 \times \text{IGE}$  following the results in [Lefgren, Sims and Lindquist \(2012\)](#). It represents a “measure of ignorance” in our understandings of the determinants of intergenerational mobility. Other target moments, including  $\frac{\bar{y}_1}{\bar{y}_2} = 0.96$ ,  $CV(y_1) = 0.56$ ,  $CV(y_2) = 0.77$ ,  $\pi = 4.6\%$ ,  $\text{IGE} = 0.36$ , and  $e/y = 0.05$ , are derived from the Current Population Survey (CPS), the Panel Study of Income Dynamics (PSID), and the past literature on parental investments in children's education ([Lee and Seshadri 2019](#), [Daruich 2018](#)) for years closest to 2000. Because the model is just identified, these data moments will be exactly matched in the calibration procedure following Proposition 1.

The parameters of particular interest are those in the human capital production function. Combining the results on  $\{\delta_0, \delta_1, \delta_2\}$  with the observed level of  $e/y$ , I find that a one standard deviation change of teacher quality throughout ones' education leads to a rise in human capital by 1.6 percent. The implied result from the structural model here is slightly larger but broadly consistent with [Chetty, Friedman and Rock-off \(2014a\)](#), who conclude that “a one standard deviation increase in teacher quality in a single grade raises annual earnings by 1.3 percent.” The result that  $\delta_2 < 0$  is of particular importance because as discussed before, it implies that the endogenous human capital formation serves as an amplifying mechanism of the teacher selection channel and that public schooling serves as the “great equalizer” in the economy ([Agostinelli, Doepke, Sorrenti and Zilibotti 2022](#)). Using the approximation formula in [Kmenta \(1967\)](#), the implied elasticity of substitution between parental invest-

Table 3: Calibration Results

Human capital production			Preference		
		Value			Value
$\delta_0$	teacher effect (level)	-0.48	$\kappa$	teacher cost	0.21
$\delta_1$	investment effect	-0.42	$\theta$	taste shock dispersion	3.07
$\delta_2$	teacher effect (gradient)	-0.88	$\beta$	weight on children's h.c.	0.35
$A$	TFP of h.c. production	1.12			
$\rho$	residual persistence	0.22			
$\sigma_\epsilon$	ability shock dispersion	0.72			
Labor market			Equilibrium objects		
		Value			Value
			$\xi$	teacher quality	-0.64
			$w$	relative wage	2.18
$\psi_1$	skill bias (teachers)	0.73	$\mu$	average h.c.	1.15
$\psi_2$	skill bias (non-teachers)	1	$\sigma$	h.c. dispersion	0.77

*Notes:* This table displays the calibration results. See text for the identification proof and targeted moments.

ment and teacher quality is around 2 in the calibrated model. This value is consistent with existing estimates, such as 1.92 by [Blankenau and Youderian \(2015\)](#) and 2.43 by [Kotera and Seshadri \(2017\)](#).

## 4. Counterfactual Analyses

In this section, I analyze two counterfactual to better understand the role of teacher quality and human capital formation in shaping the dynamics of inequality and intergenerational mobility.

### 4.1 Performance-Based Compensation

In the first counterfactual, I permanently increase the returns to human capital by 5% in the teaching profession to mimic a performance-based compensation. The magnitude of 5% is chosen to be the same as the initial impacts that duty-to-bargain

laws had on the income dispersion among teachers in the empirical findings, albeit in a different direction. The policy change occurs at  $t = 1$ . Figures 1a to 1d shows the transition path of CV(teacher), CV(non-teacher), teacher quality  $\xi$ , and IGE from the original economy to the new steady state.

I find that inequality within the teaching profession jumps initially. But in the long-run steady-state, only two-fifth of the initial impacts on CV(teacher) survive. In contrast, CV(non-teacher) decreases drastically by 3%, reflecting changes in the dispersion of human capital  $\sigma$ . Intergenerational elasticity of earnings falls from 0.36 to 0.27, due to the fact that higher teacher quality diminishes the role of private parental investments and hence intergenerational persistence of human capital.

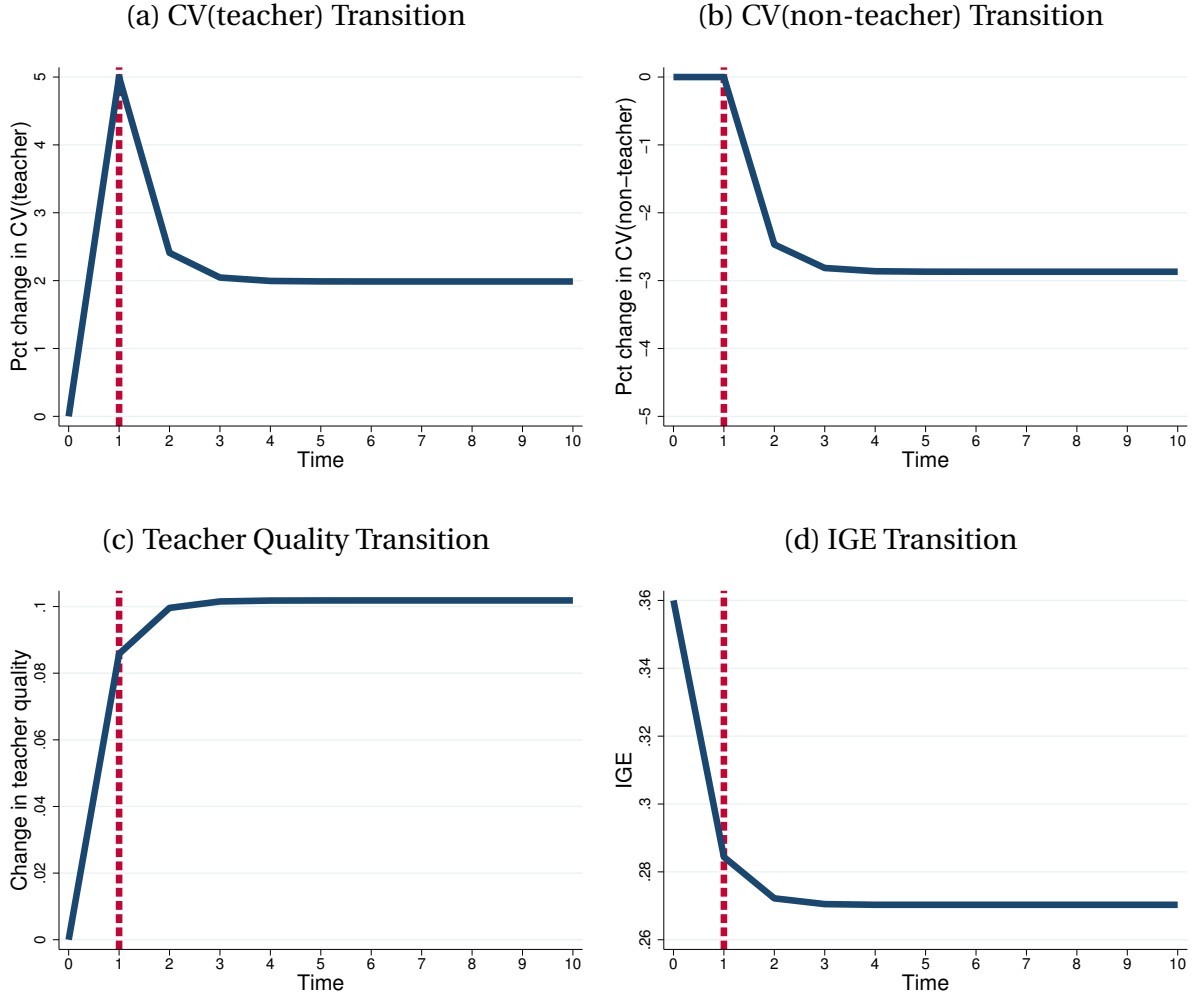
The results also indicate that the magnitude of these effects vary along the transition path. In particular, empirical analyses that focus on effects on current generation ( $t = 1$ ) or next generation ( $t = 2$ ) could overstate the effects of performance-based compensation on CV(teacher) and understate the dynamic effects on teacher quality  $\xi$ , non-teacher inequality CV(non-teacher), and intergenerational mobility IGE.

## 4.2 Skill-Biased Technical Change

In the second counterfactual, instead of changing  $\psi_1$ , I let  $\psi_2$  rise by 1% permanently to mimic a small skill-biased technical change (SBTC), i.e., the “convexification” of the non-teaching labor market (Autor, Goldin and Katz 2020). Like the case before, the rise in  $\psi_2$  occurs at  $t = 1$ . Figures 2a to 2d shows the transition path of CV(teacher), CV(non-teacher), teacher quality  $\xi$ , and IGE from the original economy to the new steady state.

I find that when  $\psi_2$  increases, it not only raises inequalities within non-teachers but also those within teachers, reflecting changes in  $\sigma$ . Higher returns to human capital in non-teaching occupations attract the most talented workers and reduce teacher quality, with the effects being much larger in the long run (see Figure 2a). Interestingly, intergenerational elasticity of earnings increases for two reasons. The first reason is the same as that in the previous counterfactual - reduced teacher quality raises

Figure 1: Increasing Return to Human Capital Among Teachers



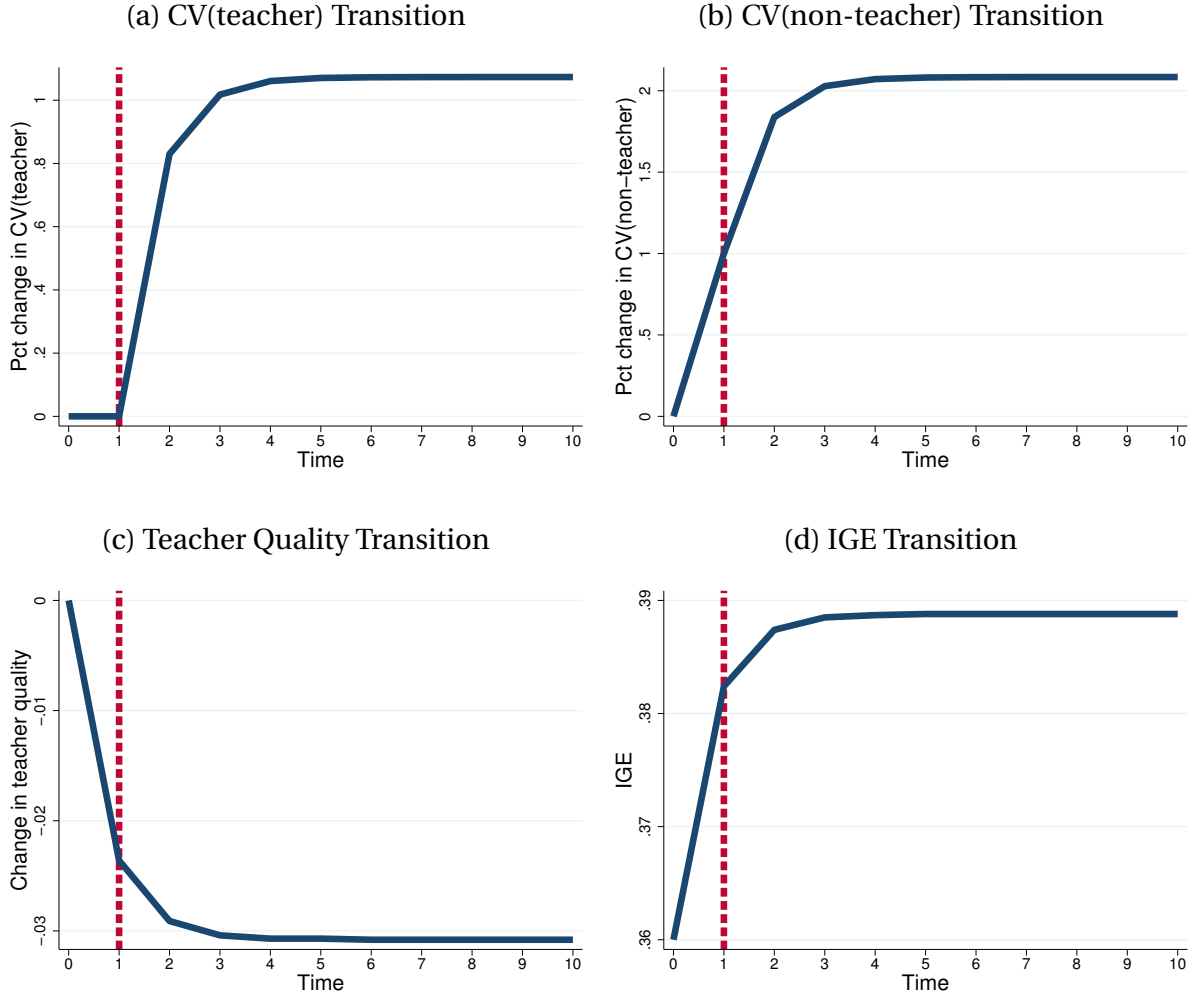
Notes: These figures plot the transition path of CV(teacher), CV(non-teacher), teacher quality  $\xi$ , and IGE following a 5% permanent increase of  $\psi_1$  in the steady-state economy.

the role of parental investments and hence intergenerational persistence. The second reason is that the dispersion of parental income is also greater due to higher  $\psi_2$ , magnifying disparities in parental investments.

To better understand the relative importance of these different channel, I conduct a model-based decomposition of  $CV(y_2)$  in the following steps:

1. First, because  $CV(y_2) \equiv \sigma\psi_2$ , I decompose  $CV(y_2)$ :

Figure 2: Skill-Biased Technical Change



Notes: These figures plot the transition path of CV(teacher), CV(non-teacher), teacher quality  $\xi$ , and IGE following a 1% permanent increase in  $\psi_2$  in the steady-state economy.

$$\underbrace{CV(y_2)' - CV(y_2)}_{\text{changes in inequality}} = \underbrace{\sigma'(\psi_2' - \psi_2)}_{\text{direct effect}} + \underbrace{(\sigma' - \sigma)\psi_2}_{\text{indirect h.c. dist.}}$$

I find that the direct effect of changing  $\psi_2$  accounts for 48% of total changes in  $CV(y_2)$  in the long run, with the rest being explained by changing  $\sigma$ .

2. To understand what drives changes in  $\sigma$ , I conduct a decomposition of IGE because in the steady-state  $\sigma$  is proportional to  $\sqrt{1 - IGE^2}$ . The formula  $IGE =$



$\rho + \psi_2(\delta_1 + \delta_2\xi)$  motivates the following decomposition:

$$\underbrace{\psi'_2(\delta_1 + \delta_2\xi') - \psi_2(\delta_1 + \delta_2\xi)}_{\text{changes in IGE}} = \underbrace{\psi_2\delta_2(\xi' - \xi)}_{\text{teacher quality}} + \underbrace{(\delta_1 + \delta_2\xi')(\psi'_2 - \psi_2)}_{\text{parental income}}$$

I find that teacher quality channel accounts for 94% of changes in IGE with the rest being explained by changes in parental income dispersion.

These decomposition results lead to an intriguing policy implication. Suppose  $\psi_2$  increases by 1%, one can counteract its contemporaneous effects on teacher quality by also raising  $\psi_1$  by 1%. But with the additional channel through parental income, this 1% increase is not enough to maintain teacher quality in later periods. Therefore, to neutralize the effects of the SBTC, the returns to human capital in the teaching profession needs to rise *relatively more* than that in the non-teaching profession. If instead, policymakers or teacher unions shield teachers from rising inequality elsewhere by reducing  $\psi_1$ , income inequalities among non-teachers will become even more severe in the future.

## 5. Robustness

In this section, I discuss the robustness of the main results.

### 5.1 Mapping DTB Laws to the Model

As discussed before, one potential worry is that variations in employment and wages following DTB laws could also reflect changes in relative wages  $w$  or entry barriers  $\kappa$ . In that case, instead of Equations (18') and (19'), we have

$$\begin{cases} \Delta \log(y_1) = \Delta\psi_1[\mu + \sigma^2(\psi_1 + \theta(2\psi_1 - \psi_2))] + \Delta w \\ \frac{\Delta\pi}{\pi} = \Delta\psi_1 \cdot (\theta\mu + \sigma\theta\xi) + \theta(\Delta w + \Delta\kappa) \end{cases} \quad (22)$$

Note that potential changes in  $w$  and  $\kappa$  does not affect the interpretation of other

equations including (16'), (17'), and (21) because they do not alter teacher quality  $\xi$  in the model. They, however, do affect the calibration of other parameters. I divide the analysis into three cases.

First, suppose DTB laws affect entry barriers  $\kappa$  but not relative wage  $w$ . Then Equation (18') survives but equation (19') is contaminated because I do not have a direct measure of  $\Delta\kappa$  in the data. In this case, I need to calibrate  $\theta$  outside of the model and choose a value from the literature. An important insight here is that different value of  $\theta$  does not affect the calibration of other variables except  $\{\delta_0, \delta_2, \xi, w, \kappa\}$ , and the results in all counterfactuals remain unchanged.

To see this, suppose  $\theta$  is doubled. To make Equation (17') hold,  $\delta_2$  needs to halve. Similarly,  $\delta_0$  needs to halve to make Equation (16') hold.  $\xi$  needs to double because  $\xi = (\text{CV}(y_1) - \text{CV}(y_2)) \cdot \theta$ . Lastly,  $w$  and  $\kappa$  needs to adjust to maintain Equations (9) and (7). Beyond that, no other parameters need to change because  $\delta_0, \delta_2$ , and  $\xi$  enter the rest of the model, especially human capital dynamics, in a multiplicative fashion and these changes exactly cancel out.

Second, suppose DTB laws affect  $w$  but not  $\kappa$ . I can multiply the first equation in (22) by  $\theta$  and subtract the second equation to cancel out  $\Delta w$ . Then, I can proceed like the previous case by calibrating  $\theta$  exogenously. The results in counterfactuals are not affected.

Last, suppose DTB laws affect  $w$  as well as  $\kappa$ . Then the empirical results on how DTB laws affect teacher labor markets are not informative about parameters and I need to find additional calibration targets. One option is to equate the effects of a one standard deviation increase in teacher quality on children's income, which is  $(\delta_0 + \delta_2 \log(e/y)) \cdot \psi_1$  in the model, to existing empirical estimates (e.g., Chetty, Friedman and Rockoff 2014a). Then, I can calibrate  $\theta$  exogenously, and the counterfactual results are again not affected. As discussed before, when I compare teacher value added in the model to Chetty, Friedman and Rockoff (2014a) after calibration, the two values are quite similar.

To sum up, while potential changes in  $w$  and  $\kappa$  threaten the identification of  $\theta$ , the

counterfactual results will not be affected if I calibrate  $\theta$  exogenously outside of the model.

## 5.2 Heterogeneous Preference

In the baseline model, I have assumed that the idiosyncratic preference shock  $\nu$  is not correlated with human capital  $h$ . Suppose instead there is a systematic relationship between taste and human capital, consider

$$\nu = \psi_3 \log(h) + \tilde{\nu}$$

where  $\psi_3$  governs the degree of correlation and  $\tilde{\nu}$  is an idiosyncratic shock.

Then, individual's choice problem becomes

$$\max_{j \in \{1,2\}} \mathbb{1}_{j=1} (\log(wh^{\psi_1} \cdot \kappa \cdot h^{\psi_3}) + \tilde{\nu}) + \mathbb{1}_{j=2} \log(h^{\psi_2})$$

This leads to changes in the formulas of  $\pi$  and  $\xi$  where  $\psi_1$  needs to be replaced by  $\psi_1 + \psi_3$ , which also implies that there is an additional parameter  $\psi_3$  to be calibrated.

One solution is to equate the effects of a one standard deviation increase in teacher quality on children's income, which is  $(\delta_0 + \delta_2 \log(e/y)) \cdot (\psi_1 + \psi_3)$  in this case, to existing empirical estimates (e.g., [Chetty, Friedman and Rockoff 2014a](#)). This gives an additional condition that allows us to separately identify  $\psi_3$  from  $\psi_1$  (which is identified using the dispersion of teachers' earnings). As discussed before, when I compare teacher value added in the model to [Chetty, Friedman and Rockoff \(2014a\)](#) after calibration, the two values are quite similar. This implies that the main results will not be significantly affected if I allow this form of correlation between preference and human capital.

## 6. Conclusion

In this paper, I study how reward structure to teachers affects inequality and intergenerational mobility. In a model with occupation choice and child investments, I investigate the feedback mechanism between teacher quality and human capital distribution. Human capital dispersion amplifies the selection channel in determining teacher quality, and teacher quality affects the degree of dispersion itself through human capital formation. The model is identified using empirical evidence on how duty-to-bargain laws affect teacher labor market and children's long-run outcomes. In counterfactual analyses, I find that tying compensation to performance in the teaching profession raises income inequality among teachers but reduces inequality among non-teachers and improves intergenerational mobility. Teachers also play an important role in propagating aggregate shocks. In particular, I find that increasing returns to human capital among teachers could alleviate the effects of skill-biased technical change on inequalities.

Lastly, I would like to suggest that while this paper studies teachers, the same argument holds for other occupations, such as doctors and elected officials, as long as worker quality spills over to the productivity of future generations. These effects can be quantified in the same way through combining structural modeling and empirical analysis. I leave this as interesting future avenues of research.

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