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Title: How the Wage-Education Pro…le Got More Convex: Evidence from Mexico

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How the Wage-Education Profile Got More Convex: Evidence from Mexico[*]

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Abstract

In the 1990s, in many countries, wages became a more convex function of education: returns to college increased and returns to intermediate education declined. This paper argues that an important cause of this convexification was a two-stage demand-supply interaction: an increased demand for educated workers stimulated a supply response; an increased supply of intermediate-educated workers further increased the demand for college-educated workers, because these two types of labour are complementary. This argument is supported by an empirical equilibrium model of savings and educational choices for Mexico, where the degree of convexification was amplified by loosening credit constraints.

Key Words: Wage Inequality, Labour Demand and Supply.

JEL Codes: J31, J24, J23.

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1 Introduction

In the 1990s in many countries the wage-education profile convexified:[1] returns to college increased and returns to intermediate education decreased or remained substantially unchanged.[2] Efforts to explain the convexification have focused on the US and two main explanations have been proposed: increasing returns to college in a model where returns to schooling are heterogeneous (Deschenes 2002 and Lemieux 2006), and different degrees of complementarity between computer technology, skilled and unskilled labour in a "task-based technical change" model (Autor, Katz and Kearney 2006).[3]

In the US wages by education convexified at a time of modest changes in the supply of labour (Goldin and Katz 2007); consistently, both previously proposed explanations of the US convexification have taken the supply of labour as exogenously given. On the contrary, in several low and middle-income countries wages convexified while the supply of workers with intermediate and higher education increased in response to a growing demand for educated labour.

In this paper I relax the assumption of exogenous labour supply and I explain the convexification within a framework where educational choices respond to changes in the returns to schooling. The core argument is based on a two-way interaction between the demand and the supply of workers with different levels of education: an initial rise in the demand for workers with intermediate and college education increased the returns to both these two types of educated workers and gave incentives to invest in human capital. A reduction of credit constraints allowed the supply of workers with intermediate education to rise, which further increased the demand for college graduates since workers with intermediate and with

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[1]Lemieux (2006, 2007) and Deschenes (2002) for the US; Lopez Boo (2008) for Argentina; Metha, Felipe, Quising and Camingue (2007) for Thailand, Philippines and India; Liu (2006) for Vietnam; Söderbom, Teal, Wambugu and Kahyarara (2006) for Kenya and Tanzania; Bouillon, Legovini and Lustig (2005) for Mexico; Blom, Holm-Nielsen and Verner (2001) for Brazil; Schady (2001) for the Philippines.

[2]Consistently with the convexification of the wage-education profile, the distribution of wages has been characterized by divergent trends in upper- and lower-tail inequality: the 90th-50th percentile ratio of hourly wages increased, while the 50th-10th ratio declined or increased much less (e.g. Goos and Manning 2003 for the UK; Goldin and Katz 2007, Autor, Katz and Kearney 2006, Anderson, Tang and Wood 2006 and Wood 2002 for the US; Binelli and Attanasio 2010 for Mexico).

[3]The convexifcation of the wage-education profile has also been studied in the context of the long run theory of equilibrium wage functions deriving the theoretical prediction of a convex relationship between the skill-intensity of an occupation and its marginal rate of return Mookherjee and Ray (2010).

college education are complementary in production. As a result, returns to college increased and returns to intermediate education declined.

The argument is investigated in the context of Mexico, a middle-income country where the convexification was very pronounced: between 1987 and 2002 the wage gap between workers with higher (college or more) and intermediate education increased by 73%, and the wage gap between workers with intermediate and basic compulsory education declined by 15%. This convexification was driven by a substantial reduction of the level of wages of workers with intermediate education who faced a wage decrease of 5%. In the same years, the demand for educated workers increased by 1.35% per year, while the supply of workers with intermediate and with higher education increased, respectively, by 15% and 7%.

These supply changes could have caused the convexification by altering the composition of workers, or by changing the prices of education because of the equilibrium effects of changes in the supply of labour on wages. In order to disentangle the composition and price effects on wages, I develop a model in which the supply of workers with basic, intermediate and higher education reacts endogenously to changes in labour demand and market wages depend on education prices, individuals' age and ability. The setting is an incomplete market, dynamic model of savings and educational choices where the interest rate is taken as given and the production function allows for different elasticities of substitution between workers with basic, intermediate and higher education. Savings and education choices are made by altruistic parents that face credit constraints.

I estimate the wage equations, the production function, and the distribution of wealth and education, and I calibrate the rest of parameters. I find substitution elasticities between aggregate human capitals that are consistent with the complementarity between intermediate and higher education. I then use model's simulations to study the determinants of the convex wage shift by comparing the steady state wages that the model predicts in a baseline scenario that matches the Mexican economy in 1987 and in different counterfactual scenarios characterized by an increased demand for skilled labour.

The simulations show that the convexification was driven by changes in the prices of education due to a two-way interaction between changes in the demand and in the supply of labour: a relaxation of the credit constraints allowed the supply of labour to respond to

the increased demand for educated workers, which, because of the complementarity between workers with intermediate and with higher education, further increased the relative demand of workers with higher education and therefore their relative return while it further decreased the relative return of workers with intermediate education. This mechanism emerges against a number of alternative explanations including different ways of modelling the increased demand for labour.

The results confirm previous findings by Heckman, Lochner and Taber (1998) and Lee and Wolpin (2006) that simultaneous movements in the demand and in the supply of workers with different levels of education are important determinants of changes in relative returns. Importantly, and differently from both these previous papers, I jointly model education and saving choices under credit constraints, which I find to be the main factor affecting investment in education and via this returns to schooling.[4]

2   Wage convexification in Mexico

For the analysis of wages I use micro data from the Mexican Employment Survey (*Encuesta Nacional de Empleo Urbano* or ENEU) from 1987 to 2002. The ENEU is the only Mexican household survey continuously available since the late 1980s that collects detailed labour market information and a large array of socioeconomic characteristics; the survey covers only urban areas and collects information on both formal and informal workers that in the 1990s accounted for around half of the Mexican labour force (Maloney 2004; and Bosch and Maloney 2006; Binelli and Attanasio 2010). As such, it has been widely used for studies of the Mexican labour market, including several studies on changes in the wage distribution (e.g. Binelli and Attanasio 2010, Bosch and Manacorda 2010, and Verhoogen 2008).

The sample selection criteria follow Binelli and Attanasio (2010): I consider all adults aged between 25 and 60 that are actively working as either salaried or self-employed workers at the time of the interview in all municipalities included in the fourth quarter of each survey year between 1987 and 2002. I adjust wage data for inflation by using the Mexican

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[4]Gallipoli, Meghir and Violante (2007) also develop an equilibrium model of savings and educational choices with credit constraints. Their model has a much richer structure than the one developed here.

national CPI of June 2002, and I compute log hourly real wages for three education groups: "basic education", which includes all workers with uncompleted intermediate education, "intermediate education", which includes all workers with completed intermediate education and up to uncompleted college, and "higher education", which includes all workers with completed college or more. Appendix A1 provides a brief description of the ENEU, all details on the sample selection criteria and on how I compute individual wages. Appendix A2 provides details on the Mexican education system and on the construction of the three education groups.

Figure 1: Convexification of the Mexican wage-education profile. Source: ENEU data in 1987 and in 2002.
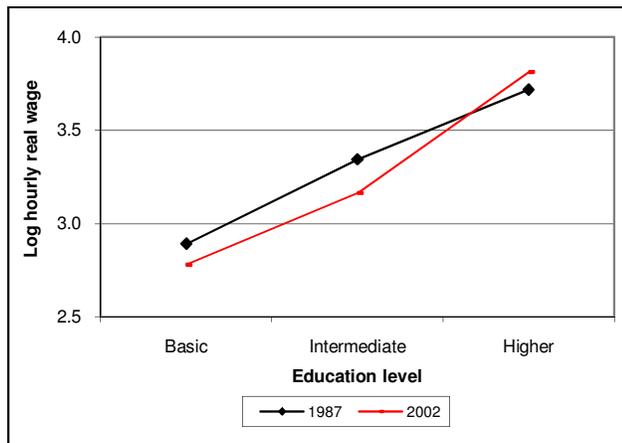

Figure 1 and Table 1 present average log hourly real wages for each of the three education groups. Between 1987 and 2002 the education-wage profile convexified: the college-intermediate log wage gap increased by 73% and the intermediate-basic log wage gap decreased by 15%. The absolute level of wages also changed differentially: it increased at higher education and decreased at intermediate and at basic education. The most substantial loss was at the intermediate level where log hourly real wages fell by 5%.[5] A direct test of this convexification can be performed by estimating a standard Mincer wage equation that

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[5]Both the difference between mean wages by education in 1987 and 2002 and the changes in the wage differentials are statistically significant.

in addition to years of schooling, age and age squared includes a quadratic term of years of schooling. By estimating this equation separately for 1987 and for 2002 I find that the quadratic term of years of education is positive and highly statistically significant in both years, and that it is higher in magnitude in 2002 with respect to 1987, which confirms that the curvature of the returns to education functions has increased, and the returns have became more convex. These differential wage changes by education are consistent with changes by percentile of the wage distribution: unreported data, all available upon request, show that the 90th-10th ratio of hourly real wages increased by around 19% and the 50th-10th ratio decreased by around 8%.

% change ENEU data 1987-2002			
Log wage level		Log wage differential	
Basic	−4%		
Intermediate	−5%	Higher-Intermediate	73%
Higher	3%	Intermediate-Basic	−15%

Table 1: Growth of log hourly real wages by level of education and of log relative wages between 1987 and 2002 in Mexico.

The sampling scheme of the ENEU survey has changed over time with a number of smaller municipalities having progressively entered the sample. One may worry that changes in the composition of the ENEU sample could affect the results. An alternative to using all municipalities included in each survey year is to restrict the sample to the 96 municipalities that have been consistently surveyed in each year between 1987 and 2002. However, wages by education are not significantly affected by this restriction and the wage convexification remains evident: wages of higher relative to intermediate education increased by 83%, wages of intermediate relative to basic education decreased by 27%, and wages of workers with intermediate education decreased by 3%. Therefore, in the rest of the paper, I use the sample that includes all municipalities in each survey year. Results using the restricted sample are very similar and are available from the author upon request.

A vast empirical literature has documented two distinct episodes of changes in Mexican wage inequality: a period of rising wage inequality from the end of the 1980s to the mid 1990s and a period of stable or even decreasing inequality in the second half of the 1990s (e.g. Binelli and Attanasio 2010, and Bosch and Manacorda 2010). Consistently with the

previous literature, the data show that the wage differential between workers with intermediate and with basic education increased until 1994 and decreased sharply from 1997. On the contrary, the wage differential between workers with higher and with intermediate education increased steadily between 1987 and 1996 and it then only decreased slightly by less than 1%.[6]Therefore, overall, between 1987 and 2002, relative wages to higher education increased while relative wages to intermediate education declined. It is this wage pattern that this paper is set to explain.

These changes in relative wages took place over a period of sixteen years that were characterized by a significant increase in the supply of workers with intermediate and with higher education. Between 1987 and 2002 the proportion of the adult working population aged between 25 and 60 with intermediate education smoothly increased from around 30% to 45%, and the proportion of the adult working population with higher education increased from around 10% to 17%. These supply changes are consistent with the findings of Behrman, Birdsall and Szekely (2007) and Gasparini, Galiani, Guillermo and Acosta (2011) that document a substantial increase in the stock of educated labour in sixteen Latin American countries where wages convexified.

The entrance of the new cohorts of educated workers could have induced the wages to convexify by changing the composition of workers by level of education, as well as by changing the equilibrium prices of education due to the interplay between the demand and the supply of educated labour. Several previous analysis have studied the role of the demand and the supply of labour to explain wage inequality within a standard Katz and Murphy (1992) framework, which relies on the assumption that observed changes in wages and in labour supply measure, respectively, changes in education prices and in human capital.[7] Differently, and following an extensive literature that started with the seminal contribution of Heckman, Lochner and Taber (1998), I study labour demand and supply with an equilibrium model that allows to disentangle the role of changes in prices and composition. In particular, I develop a model in which the supply of workers reacts endogenously to changes in labour demand and market wages depend on education prices, individuals' age and ability.

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[6]All results are available upon request.

[7]Three examples for Latin American are Raymundo, Esquivel, and Lustig (2012) and Montes Rojas (2006) for Mexico, and Gasparini, Galiani, Guillermo and Acosta (2011) for sixteen Latin American countries.

There is a vast empirical literature on wages and education in Mexico in the 1990s. With respect to this literature, both the object of interest and the approach taken in this paper are novel. The vast majority of the previous contributions have been focusing on the increase in the premium to higher education rather than on the convexification, and all have explained the rise in this premium with either changes in the supply or in the demand of skills ignoring the equilibrium effects of changes in the supply of education on wages. The "supply-side" literature focuses on financial constraints on educational choices and self-selection on ability into higher education as two alternative explanations of the increase in the relative wage of higher versus intermediate education. Testing these two alternative explanations, Jacoby and Skoufias (2002) find parental income being an important determinant of college attendance, which is indirect evidence of credit constraints, and weak evidence of selection bias. The "demand-side" literature focuses on the impact of trade liberalization and a series of labor market reforms promoted in Mexico in the 1990s. These reforms changed the structure of production and made the economy more open to foreign investment. The reform effort culminated in 1994 when Mexico became a member of the Organization for Economic Cooperation and Development (OECD) and entered the North American Free Trade Agreement with the US and Canada. In the same year Mexico was hit by a severe financial crisis, the "Peso crisis", which resulted into a massive devaluation of the national domestic currency. The recovery from the crisis was rather quick and by the end of 1995 Mexico had reentered the international capital markets. The reform effort and the opening to foreign investment resulted into an increase use of skilled labour and in the production of skill-intensive goods. Most empirical studies have focused on the sharp increase in the skill premium in the first half of the 1990s and have found evidence of a technological change that increased the demand for skilled labour (Verhoogen 2008), and a positive impact of trade opening on the skill premium (Hanson and Harrison 1999).

Rather than the increase in the skill premium, the object of interest of this paper is the convexification, that is the contemporaneous increase in the relative wages of higher educated and decrease in the relative wages of intermediate educated, which happened in the decade of the 1990s rather than in either the first or in the second half of the decade. I will therefore develop an equilibrium model that allows to quantify the effects of changes in the supply of

education on wages between 1987 and 2002.

3 The model

Mexico is a country where education choices are still predominantly made by parents and children's work is often used to supplement household income (López Villavicencio 2005). Therefore, I develop a model that has a dynastic structure where households consist of a child and a parent that makes all savings and education choices.

3.1 Supply side: household decision problem

At each time t the economy consists of overlapping generations of parents and children that live together for four periods, which reproduce the four main education cycles in Mexico: pre-school and three periods necessary to complete basic, intermediate and higher education.[8]

Each individual lives for eight periods, four as a child and four as a parent. As a child the individual lives with the parent that works full time and maximizes utility, which is a function of joint household consumption. In the first period the child is in pre-school; in the second period the child is sent to compulsory basic education; in the third and fourth period the child can be sent either to school or to work. At the end of the fourth period the parent retires and leaves a bequest of financial assets to the child who starts the adult life with the level of education completed during childhood and an amount of assets given by parental bequest.

Labour supply is perfectly inelastic and wages clear the labour markets. The wage of an individual i with education level j and age a in period t is given by:

$$w_{j,a,t}^i = p_{j,t} * \exp(e_{j,a,t}^i) \qquad j = 1, 2, 3 \tag{1}$$

with

$$e_{j,a,t}^i = \eta^i + g_j(age_t^i) + z_{j,a,t}^i \tag{2}$$

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[8] For simplicity the length of each period is assumed to be the same and equal to seven years in order to match the average working life of adult Mexican workers of around thirty years.

where $j = 1, 2, 3$ denotes the education level from basic up to higher education. Wages depend on the price of education, $p_{j,t}$, which is the equilibrium outcome of changes in the demand and in the supply of labour, and on individual characteristics that are summarized by individual labour efficiency, $e^i_{j,a,t}$, which is a function of ability, η^i, an education-specific polynomial in age, $g_j(age^i_t)$, and an i.i.d. uninsurable shock, $z^i_{j,a,t}$ assumed to be normally distributed with mean zero and variance $\sigma^2_{z_{j,a,t}}$. The $g(.)$ polynomial reflects the growth of wages with experience, and z captures earnings' volatility and uncertainty, which affected wage changes in Mexico in the 1990s.[9] Individuals' ability endowment represents the permanent component of human capital. It is a measure of ability and all unobservable family background factors that have a permanent impact on human capital. Consistently with the high correlation between measured ability of parents and children in Mexico, each individual inherits at birth the ability endowment of her parent and passes it over to her own child.[10]

Omitting for simplicity the t time index, parental maximization problem is given by:

$$V_a(X_a) = \max_{\{c_a, I_a\}_{a=\underline{a}}^{a=\overline{a}}} E \left\{ \sum_{a=\underline{a}}^{\overline{a}} \beta^{a-\underline{a}} U(c_a) + \beta^3 \lambda V_{\underline{a}}(X_{\underline{a}}) \right\} \tag{3}$$

$$s.t. \quad A_{a+1} = A_a(1+r) + w_{j^P,a} + \left[(1-I_a)w_{j^C,a} - I_a F_{j^C} \right] - c_a \tag{4}$$

$$j^C_{a+1} = \begin{cases} j^C_a + 1 & if \ I_a = 1 \\ j^C_a & if \ I_a = 0 \end{cases} \quad \forall \ a = \overline{a} - 1, \overline{a} \tag{5}$$

$$A_a \geq -B_a \quad \forall \ a = \underline{a}, ..., \overline{a} - 1 \tag{6}$$

$$A_a \geq 0 \quad a = \overline{a} \tag{7}$$

where c_a denotes joint household consumption at age a, and X_a is the vector of state variables at age a, which includes the level of parental and child education, j^P and j^C_a, the

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[9]The most significant event that affected wage volatility in Mexico was the Peso crisis of 1994, which has been identified as an important determinant of changes in wage inequality (Verhoogen 2008).

[10]By using Raven test scores as a proxy for individual ability, data from the Mexican Family Life Survey in 2002 show that the correlation between mother and father's Raven scores and their children's scores is above 80%.

amount of financial assets at age a, A_a, the vector of current and future education prices forecasted from age a onwards, $p(a)$, the ability endowment, η, and the idiosyncratic shock to wages, z_a. λ is the degree of parental altruism, which is strictly greater than zero consistently with the empirical evidence showing that Mexican parents care about their children's utility (Schluter and Wahba 2008). $\underline{a}$ ($\bar{a}$) denotes the age of the parent at the start (end) of the adult life, and $V_{\underline{a}}(.)$ is the child's lifetime utility once adult.

E denotes expectations that reflect uncertainty due to the presence of the uninsurable idiosyncratic shocks to earnings. The utility function is assumed to be strictly increasing and concave in consumption, so that absolute risk aversion is decreasing in individual's wealth, the impact of risk on investment decisions being higher for poorer than for wealthier households.[11]

Parents maximize utility under four main constraints. Equation (4) is a standard period budget constraint with the term in square brackets switching on when child education becomes a choice variable: if the child is sent to work, the parent receives the child's wage, $w_{jC,a}$; if the child is sent to school, the parent pays the fixed costs, F_{jC}, for the j^C schooling level attended by the child. Equation (5) defines the law of motion of child's education. Equation (6) is a borrowing restriction imposing a limit B_a on the amount of net indebtedness at age a. Equation (7) is a terminal condition that prevents parents from leaving debts to their children.

The borrowing limit, B_a, can take any value between zero, which corresponds to the maximum level of credit constraints of no possible borrowing, and an upper bound that is given by the present discounted value of lifetime earnings at age a under the lowest possible realization of individual labour efficiency, that is under the lowest possible realization of the idiosyncratic shock z. The upper bound represents the maximum amount that an individual will be able to repay without violating the no-debt condition specified in equation (7).[12]

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[11] The utility function is assumed to take a simple CRRA formulation:
$$U(c) = \frac{(c)^{1-\gamma}}{1-\gamma}$$
where γ is the reciprocal of the intertemporal elasticity of substitution.

[12] The empirical distribution of z_j is defined over a finite support with a minimum value, $\underline{z}_j$, and a maximum value, $\bar{z}_j$. The value of the upper bound arises naturally from the assumption that the utility function satisfies the Inada condition $\lim_{c \to 0} U(c) = -\infty$ and that parents have to repay all debts before retirement.

3.2 Demand side: aggregate production function

The representative firm operates a constant returns to scale technology production function over physical and human capital:

$$Y_t = Z_t K_t^\alpha HH_t^{1-\alpha} \tag{8}$$

where Y_t denotes aggregate output, K_t is aggregate physical capital and HH_t is aggregate human capital.[13] α denotes the share of physical capital in production and Z_t is the technology factor that is normalized to one in all years. I assume that the economy is small and open to the world financial markets. There is no labour migration while capital flows in or out of the country so that the marginal product of physical capital equals the world interest rate, r.

I specify HH_t as a nested CES function of unskilled (H_u), and skilled (H_s) human capital:

$$HH_t = [(1 - \delta_{s,t})H_{u,t}^\rho + \delta_{s,t}H_{s,t}^\rho]^{\frac{1}{\rho}} \tag{9}$$

where $H_{u,t} = H_{1,t}$, and $H_{s,t}$ is a CES composite of $H_{2,t}$ and $H_{3,t}$:

$$H_{s,t} = [(1 - \alpha_{3,t})H_{2,t}^\theta + \alpha_{3,t}H_{3,t}^\theta]^{\frac{1}{\theta}} \tag{10}$$

The time-varying and education-specific parameters δ and α in equation (9) and (10) denote the shares of the human capital factors in production and reflect variations in the productivity and in the demand of the different inputs. The parameters ρ and θ determine the elasticity of substitution between human capital pairs. Using the definition of the direct elasticity of substitution, we obtain that $ES_{u,s} = ES_{1,2} = ES_{1,3} = \frac{1}{1-\rho}$, and $ES_{2,3} = \frac{1}{1-\theta}$.[14]

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[13] This specification of the production function assumes that there are no complementarities between physical and human capital. This assumption is motivated by the near-constancy of the share of physical capital in production estimated for Latin America in the 1990s (Bosworth, 1998, Harrison, 1996 and Hoffman, 1993).

[14] There are three ways of nesting three human capital inputs within a CES aggregate: $\widetilde{HH}_1 = \Gamma_1(H_3, \Gamma_2(H_2, H_1))$, $\widetilde{HH}_2 = \Gamma_2(H_2, \Gamma_2(H_3, H_1))$ and $\widetilde{HH}_3 = \Gamma_3(H_1, \Gamma_2(H_2, H_3))$, where Γ_1, Γ_2 and Γ_3 are CES aggregates. I have chosen the $\widetilde{HH}_3$ nesting since the restrictions imposed by the $\widetilde{HH}_1$ and $\widetilde{HH}_2$ nestings contrast with the factor elasticities previously estimated for Latin America, which show that the elasticity of substitution between higher and intermediate education differs from the elasticity of substitu-

Labour income is measured in efficiency units and the aggregate stock of human capital j in year t, $H_{j,t}$, is given by the sum of the efficiency weighted individual supply of education level j, $h^j_{i,t}$:

$$H_{j,t} = \sum_i h^j_{i,t} \qquad j = 1, 2, 3 \tag{11}$$

Under the assumption of perfectly competitive markets and profit maximization by firms, the price of education level j in year t, $p_{j,t}$, is given by the marginal product of the jth aggregate human capital. By taking the ratios of the marginal products, I can derive the expressions for the relative prices of education:

$$\frac{p_{2,t}}{p_{1,t}} = \frac{\delta_{s,t}}{(1 - \delta_{s,t})}(1 - \alpha_{3,t})\left(\frac{H_{1,t}}{H_{2,t}}\right)^{1-\rho}\left\{(1 - \alpha_{3,t}) + \alpha_{3,t}\left[\frac{H_{3,t}}{H_{2,t}}\right]^\theta\right\}^{\frac{\rho-\theta}{\theta}} \tag{12}$$

$$\frac{p_{3,t}}{p_{2,t}} = \frac{\alpha_{3,t}}{(1 - \alpha_{3,t})}\left(\frac{H_{3,t}}{H_{2,t}}\right)^{\theta-1} \tag{13}$$

$$\frac{p_{3,t}}{p_{1,t}} = \frac{\delta_{s,t}}{(1 - \delta_{s,t})}\alpha_{3,t}\left(\frac{H_{1,t}}{H_{3,t}}\right)^{1-\rho}\left\{\alpha_{3,t} + (1 - \alpha_{3,t})\left[\frac{H_{2,t}}{H_{3,t}}\right]^\theta\right\}^{\frac{\rho-\theta}{\theta}} \tag{14}$$

The degree of complementarity between intermediate and higher education is an important determinant of the changes in relative prices. An increase in the amount of human capital at intermediate level has both a standard supply effect (SE) and a complementarity effect (CE). The standard SE is clear from the human capitals' ratio in round brackets in equation (12) and (13). For a given supply of basic and higher human capital, an increase in H_2 decreases the relative price of intermediate with respect to basic education and increases the relative price of higher with respect to intermediate education. The CE is given by the term in curly brackets in equation (12) and (14). The size of the SE and CE effects depends on the magnitude of the elasticity parameters, ρ and θ. If $\rho > \theta$, that is if higher and intermediate education are more complementary than higher and basic (or intermediate and

tion between either higher or intermediate and basic education (Manacorda, Sanchez-Paramo and Schady 2010).

basic), an increase in H_2 further decreases the relative price of intermediate with respect to basic education and increases the relative price of higher with respect to basic education.

3.3 Equilibrium steady state

Given an initial distribution of ability, financial assets and education, and the world interest rate, an equilibrium steady state is given by a vector of education prices, $p = [p_1, p_2, p_3]$, aggregate labour inputs, $H = [H_1, H_2, H_3]$, parental decision rules for consumption and education choices, $[c_a, I_a]$, individual labour supply of education j, j_a, individual labour efficiency, $e_{j,a}$, age and education specific measures, $\varphi_{j,a}$ for $a = \underline{a}, ..., \overline{a}$, such that:

1. Given the prices $[p_1, p_2, p_3]$, the contingent plans c_a and I_a solve the household maximization problem (3) subject to (4) to (7).

2. Given the prices $[p_1, p_2, p_3]$, firms choose optimally the production factors and prices are marginal productivities:

$$p_j = \frac{\partial Y}{\partial H_j} \quad \forall j$$

3. Labour markets clear:

$$H_j = \sum_{a=\underline{a}}^{a=\overline{a}} \int_S (j_a(s) * \exp(e_{j,a,t})) d\varphi_{j,a}(s) \quad \forall j$$

where S defines the state vector at age a minus the education states, i.e. $S \equiv (A_a, p(a), \eta, z_a)$.

The steady state is computed by solving the model recursively by standard backwards induction from the last to the first period of adult life. All details of the solution algorithm are available upon request.

3.4 Determining the parameters of the model

The ideal data set to estimate the model would combine micro data on the earnings of workers, their life-cycle consumption and wealth holdings, and macro data on prices and aggregates. Using the micro data joined with the aggregate prices, I could estimate the parameters of the household decision problem and construct human capital aggregates that

could be used to determine the output technology. Two obstacles prevent implementing this approach. First, I lack information on consumption linked to labour earnings over many years. Second, the data on market wages do not reveal education prices, as it is evident from the distinction between w and p in equation (1), so it is not possible to estimate aggregate stocks of human capital using wage data directly.

To circumvent the first limitation, I set the initial distribution of wealth to match the distribution of wealth in the Mexican Expenditure Survey (*Encuesta Nacional de Ingresos y Gastos de los Hogares* or ENIGH), and the distribution of education to match the wage data from the ENEU survey in 1987, and I choose intertemporal substitution parameters in consumption to be consistent with those reported in the empirical literature. I set the borrowing limit B to zero, which corresponds to the maximum level of credit constraints, and I calibrate each fixed education cost F_j to match the share of workers aged between 25 and 60 with the *jth* level of education in the ENEU data for 1987. To circumvent the second limitation, I follow the standard method developed by Heckman, Lochner and Taber (1998) of using wage data to infer education prices and estimate human capital aggregates, which can then be used to estimate the parameters of the production function.

For conciseness all details of the calibration and estimation of the model are presented and discussed in Appendix B. The most important result concerns the production function: I estimate the elasticity of substitution between workers with higher and with intermediate education to be lower than the elasticity of substitution between workers with either higher or intermediate and basic education, which is consistent with production complementarities between intermediate and higher education.

3.5   Simulations

Having being solved and estimated, I use the model to study the factors that induced the wage profile to convexify. I do so by comparing the steady state wages by level of education that the model predicts in a baseline scenario that matches the Mexican economy in 1987 and in different counterfactual scenarios characterized by an increased demand for educated labour.

3.5.1 Exogenous labour supply

The increasing share of workers with intermediate education that between 1987 and 2002 went up from 30% to 45% (see Section 2) is consistent with the decreasing trend in the relative returns to intermediate education, while the increase share of workers with higher education from 10% to 17% at a time of an increase in their relative wages is evidence of a demand increase that more that outweighed the supply increase for this education group. As already discussed in Section 2, a vast empirical literature has documented an increased demand for educated labor in the 1990s in Mexico, and all studies agree that in the 1990s Mexico underwent a structural change towards the use of skilled labor in production. Consistently with this finding, I also find that between 1987 and 2002 the share of skilled and higher educated labour used in production (δ_s and α_3 in equation (9) and (10)) have increased, respectively, by 1.35% and 2.62% a year (Section B1.2 in Appendix B).

Could the increased demand for educated labour have changed the education prices and produced the convexification without the supply of labour playing any major role?

In order to isolate the effect of the demand's change, I compute a baseline steady state that matches the linear wage-education profile in 1987 and starting from this baseline I increase the demand for educated labour while keeping the supply of labour by education fixed at the baseline's levels. I compute three different steady states that correspond to the increase in the share of skilled labour that I have estimated from the data: scenario I that I obtain by increasing δ_s by 1.35% for each year between 1987 and 2002, scenario II by increasing α_3 by 2.62% a year, and scenario III by increasing both δ_s and α_3. Table 2 presents the percentage changes of the equilibrium log wages between 1987 and 2002 in the ENEU data, and in scenario I, II, and III with respect to the baseline; Table 3 reports the corresponding percentage changes in relative wages.

In scenario I, II and III labour supply is taken as exogenously given and all changes in the prices of education are due to the increased demand for educated labour. Equations (12) and (13) show that an increase in δ_s increases the equilibrium price (and therefore the equilibrium wage) of intermediate and higher education relative to basic education, while an increase in α_3 increases the wage differential between higher and intermediate education

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and decreases the wage differential between intermediate and basic education. Consistently, relative wages to higher and to intermediate education increase in scenario I and III, while they have a divergent trend in scenario II. Scenario II matches the changes in relative wages observed in the data, but it is unable to match the decrease in the level of intermediate and basic wages.

% change log wage level relative to baseline	Data	I	II	III
Basic	−4%	6%	11%	6%
Intermediate	−5%	20%	9%	10%
Higher	3%	30%	35%	37%

Table 2: Growth of log wages by education in the data and in different scenarios with respect to the baseline. Scenario I: increased demand for skilled labour; scenario II: increased demand for higher education; scenario III: increased demand for skilled labour and for higher education. Exogenous labour supply in all scenarios.

% change log wage differential relative to baseline	Data	I	II	III
Higher versus Intermediate	73%	17%	77%	78%
Intermediate versus Basic	−15%	59%	−17%	15%

Table 3: Growth of log relative wages in the data and in different scenarios with respect to the baseline. Scenario I: increased demand for skilled labour; scenario II: increased demand for higher education; scenario III: increased demand for skilled labour and for higher education. Exogenous labour supply in all scenarios.

3.5.2 Endogenous labour supply

The simulations in the previous section show that for the size of the demand changes estimated from the data an increased demand for educated labour alone could not have produced the convexification. The next step is to explore the role of the endogenous supply of labour. From now on I will model the increased demand for educated labour as in scenario I, that is as an increased share of skilled labour (δ_s), and I will define a series of counterfactuals that allow the supply of labour to react to this increased demand.

I define a fourth counterfactual, scenario IV, which I compute by increasing δ_s by 1.35% a year and by allowing the supply of labour to react to this demand increase. The second column of Table 4 and Table 5 reports, respectively, the percentage changes in log wages and in relative wages in scenario IV with respect to scenario I.

% change log wage level	IV vs I	V vs IV	IV vs baseline
Basic	-8%	-3%	-1%
Intermediate	-22%	3%	2%
Higher	-24%	1%	13%

Table 4: Growth of log wages by education in different scenarios. Scenario IV: increased demand for skilled labour and endogenous labour supply. Scenario V: increased demand for skilled labour, endogenous labor supply and isoelastic production function.

% change log wage differential	IV vs I	V vs IV	IV vs baseline
Higher versus Intermediate	17%	-8%	36%
Intermediate versus Basic	-26%	27%	17%

Table 5: Growth of log relative wages in different scenarios. Scenario IV: increased demand for skilled labour and endogenous labour supply. Scenario V: increased demand for skilled labour, endogenous labor supply and isoelastic production function.

The comparison between scenario IV and scenario I shows the role of the endogenous supply of labour: the higher demand for skilled labour increases the returns to intermediate and to higher education and gives incentives to invest in education; accordingly, wage levels decrease. Consistently with the fixed costs of education being lower at intermediate than at higher education ($F_2 < F_3$), the supply of workers with intermediate education increases more than the supply of workers with higher education, and triggers a differential change in relative wages, which increased by 17% at higher education, and decreased by 26% at intermediate education.

The equilibrium effects of changes in labour supply on wages depends on the degree of complementarity and substitutability between aggregate human capitals. I estimate the elasticity of substitution (ES) between workers with higher and with intermediate education to be 4.4, and the ES between workers with either higher or intermediate and basic education to be 7.1 (Section B1.2 in Appendix B), which is evidence of complementarities between workers with intermediate and with higher education.[15] I assess the importance of these complementarities by comparing scenario IV with a fifth counterfactual, scenario V, which assumes an isoelastic production function where $ES_{u,s} = ES_{1,2} = ES_{1,3} = ES_{2,3} = \frac{1}{1-\rho} =$

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[15] The estimated elasticities of substitution are much higher than the typical estimates obtained from US data (e.g. Katz and Murphy 1992) but are consistent with the estimates obtained by Manacorda, Sanchez-Paramo and Schady (2010), which, to the best of my knowledge, is the only other paper to have estimated a CES production function with three levels of education for Latin America.

4.4. The third column of Table 4 and Table 5 reports, respectively, the percentage changes in log wages and in relative wages in scenario V with respect to scenario IV.

When the production function is isoelastic and only the direct supply effect operates, intermediate wages increase and the sign of the changes in relative wages is reversed - relative wages to intermediate education increase, and relative wages to higher education decrease. The comparison between the second and the third column in Table 6 shows that an endogenous labour supply and production complementarities are both important to match the differential change in relative wages that characterize the convexification. However, scenario IV is still unable to match the data: the supply of workers with intermediate education does not increase enough to allow intermediate wages to decrease, so that, with respect to the baseline economy in 1987, intermediate wages increase and both relative returns to higher and to intermediate education increase (fourth column of Table 4 and Table 5).

An important factor that affects the supply of education is the ability to borrow to finance schooling investments. In all the simulations up to now the borrowing limit B is set to zero so that borrowing is not allowed and the total amount of resources of a given household can not exceed the sum of parental wealth and total household earnings. In order to assess the role of borrowing, I define a sixth counterfactual, scenario VI, which relaxes the credit constraints to the upper bound that B can take.[16] Table 6 presents the growth of log wages and of relative wages in scenario VI with respect to the baseline.

Log wage level	VI vs baseline	Log wage differential	VI vs baseline
Basic	-1%		
Intermediate	-4%	Higher-Intermediate	48%
Higher	9%	Intermediate-Basic	-14%

Table 6: Growth of log wages by education and of log relative wages in scenario VI with respect to the baseline.

In scenario VI wages convexify: relative wages to higher education increased and relative

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[16]The internal consistency of the model allows to set an upper bound for the value that B can take at any age, which is given by the present discounted value of the lifetime earnings at age a under the lowest possible realization of the idiosyncratic education-specific shock z_j. Given the distribution of z_j defined over a finite support with a minimum value, $\underline{z}_j$, and a maximum value, $\overline{z}_j$, $\underline{z}_j$ defines the lowest possible value that z_j can take. I compute $\underline{e}^i_{j,a} = \left(\eta^i + g_j(age^i) + \underline{z}_j \right)$. At each age a, given parental education level j, $B_a = \sum_{t=0}^{\overline{a}-a} \frac{w^i_{j,a}}{(1+r)^t} = \sum_{t=0}^{\overline{a}-a} \frac{\left(p_j * \exp(\underline{e}^i_{j,a}) \right)}{(1+r)^t}$ where r is the world interest rate.

wages to intermediate education decreased, while wages decreased for those with intermediate and basic education and increased for those with higher education. As expected, the more it is possible to borrow, the higher the investment in education after compulsory schooling. Unreported results show that there is a borrowing threshold of around 40% of individuals' lifetime earnings below which the size of the supply increase of workers with intermediate education would not be big enough to match the wage changes observed in the data. The level of credit constraints appears as the main factor that affects investment in education. If the borrowing limit is set to zero and borrowing is not allowed, unreported scenarios characterized by changes in the extent of earnings' risk, as well as by changes in additional factors that affect educational and saving choices such as the degree of relative risk aversion and the degree of parental altruism are unable to match the wage changes that are observed in the data.

4 Discussion

The results of the simulations identify two main factors driving the convexification. First, production complementarities that are responsible for the differential change between relative wages of higher educated workers, which increased, and relative wages of intermediate educated workers, which decreased; second, a relaxation of the credit constrains, which allowed the supply of intermediate educated workers to increase, and thus induced mean wages for these workers to decrease as observed in the data.

In this section I first assess how much of the wage convexification is due to changes in the education prices, and I then discuss production complementarities and credit constraints. I conclude the section with a brief discussion of two factors that are not included in the model and could have contributed to the convexification.

4.1 Changes in education prices

The wage changes predicted by the model in scenario VI match closely the changes observed in the data: intermediate wages decreased by 5% in the data and by 4% in the model, while relative wages to higher education increased by 73% in the data and by 48% in the model,

and relative wages to intermediate education decreased by 15% in the data and by 14% in the model.

How much of the wage convexification is due to changes in the prices of education?

Equation (1) allows computing the changes in the prices of education, that is in the component of the wages that does not depend on age and ability. Table 7 presents the growth of the education prices and of the relative prices in scenario VI with respect to the baseline model.

% change scenario VI with respect to baseline			
Log price		Log price differential	
Basic	−2%		
Intermediate	−6%	Higher-Intermediate	75%
Higher	10%	Intermediate-Basic	−26%

Table 7: Growth of prices by education and of relative prices in scenario VI with respect to the baseline.

Both the changes in the level of prices and in relative prices are close in magnitude to the changes in wages reported in Table 6: wages and prices increase at higher education and decrease at basic and at intermediate education, and for both prices and wages the higher-intermediate differential increases and the intermediate-basic differential decreases. Interestingly, while the intermediate-basic differential decreases more in prices than in wages, the higher-intermediate differential increases more in prices than in wages, which is consistent with negative ability sorting at higher education.

The comparison between Table 6 and Table 7 suggests that the role of changes in age and ability composition is minor: the convexification was driven by changes in the prices of education. One problem with this result is that the estimates of the ability distribution are obtained using quarterly wage data with only four observations for each individual (Section B1.1 in Appendix B), and thus suffer from the incidental parameters' problem (Heckman 1981).

An alternative way to assess the contribution of changes in ability composition is to compare the changes in the wage-education profile of the cohorts of workers that made all their education choices before 1987 with the changes in the wage-education profile of the cohorts that invested in education during the 1990s. Assuming that investment in education

ends at age 25 and that individuals enter the labour market by the end of the education period, the sub-sample of workers aged 41-60 in 2002 consists of individuals that made all their schooling decisions before 1987. If changes in ability composition were driving the convexification, the wage-education profile of those that made all their schooling decisions before 1987 and were in the labour market by then should not have convexified.

I estimate a log wage equation that controls for the level of education, age and its interaction with the level of education for the sub-sample of those aged 41-60 in 2002, and I compute the predicted wage for each level of education. I estimate the same wage regression for 1987, and I compute the changes in predicted log relative wages between 2002 and 1987. I find that the log wages of those aged 41-60 in 2002 did convexify: the higher-intermediate wage differential increased and the intermediate-basic wage differential decreased. These results are consistent with the findings of a number of papers that changes in returns to education in Latin America in the 1990s were not driven by changes in ability composition (e.g. Binelli, Meghir and Menezes-Filho 2010 for Brazil).

4.2 Production complementarities

The elasticities of substitution that I estimated from the data (Section B1.2 in Appendix B) are consistent with production complementarities between intermediate and higher education. Is there empirical evidence to support this finding? The production complementarities between workers with intermediate and higher education are consistent with a two-sector economy in which a first sector employs low-skilled labour and a second sector employs semi and high-skilled labour. This structure of production provides a good description of the Mexican economy that can be characterized as being made by a formal sector of semi and high-skilled workers and an informal sector of low-skilled workers. By defining a worker as "formal" if paying social security contributions in either the private or the public sector, evidence from the ENEU shows that between 1987 and 2002 almost 80% of formal sector workers have at least completed high school education. The importance of this dual production structure is consistent with the findings of Binelli and Attanasio (2010) that show how the dynamics of wage inequality in Mexico in the 1990s are strongly correlated with changes in the size of the formal and informal sectors.

Production complementarities between middle and high-skilled workers have also been pointed out as an important determinant of changes in wage differentials by Autor, Katz and Kearney (2006). By taking the supply of education as exogenously given, and assuming that middle-skilled workers are complementary to high-skilled workers and perfect substitutes to computerization, Autor et al show that a fall in computer prices leads to a polarization of employment and earnings, and use US data to provide supporting evidence to the qualitative predictions of their model.

Autor et al's model is an example of the "task-based technical change" (TBTC) models that introduced the task dimension into the production function (Autor, Levy and Murnane 2003). The key feature of the TBTC models is the assumption that labour production factors (typically three) differ with respect to the task content of their occupations, and that there are substitutabilities between tasks performed by workers with different skills.

TBTC models have been extensively used to explain the polarization of employment and wages (e.g. Autor and Dorn 2010 for the US; Goos, Manning and Solomons 2010 for Europe), and to quantify the contribution of changes in occupations to changes in the distribution of wages (e.g. Firpo, Fortin and Lemieux 2009 for the US). Even if for Mexico there are no publicly available data with information on the task intensity of occupations, Medina and Posso (2010) apply a TBTC-type model to Mexico by assuming that low skilled workers perform manual intensive tasks, middle skilled workers perform routine intensive tasks, and highly skilled workers perform abstract tasks. Under this assumed tasks' distribution, they find some evidence of employment and wage polarization in the decade of the 1990s. If tasks data for Mexico were to become available and found to confirm the tasks' distribution assumed by Medina and Posso, their results would suggest that the production complementarities between intermediate and higher educated workers that I have estimated could be driven by complementarities between tasks performed by these two types of educated labour.

4.3 Relaxation of credit constraints

Together with production complementaries, a central role to explain the convexification is played by the relaxation of the credit constraints, which allowed the supply of workers with intermediate education to increase. While there are no available Mexican data to show

directly that increases in credit availability have led to increases in education enrollments, there are two important pieces of evidence that provide indirect support for this finding. First, there is evidence that in the 1990s education enrollment rates increased while financial support via education subsidies and scholarships remained almost non-existent and the costs of education were very high; second, there is evidence that the availability of credit to Mexican households increased.

Binelli and Rubio-Codina (2013) show that the increase in the supply of workers with intermediate education in the decade of the 1980s and 1990s in Mexico was driven by higher enrollment rates rather than by lower drop-out rates. They also show that intermediate education in Mexico is expensive. Binelli and Rubio-Codina (2013) find that the costs of attending a public high school amount to around 15% of median yearly household income, and the costs of attending a private high school amount to around 23%. At higher education average costs are at around 25% of per-capita income per student per year, which compare to an average of less than 20% for high income countries (Bloom and Murakami 2008). At the same time, in Mexico there is very little to no support in the form of students' loans and scholarships neither at the intermediate (Binelli and Rubio-Codina 2013) nor at higher education (Bloom and Murakami 2008). Consistently with the high costs of education and the lack of financial support, there is evidence that credit constraints matter for schooling decisions. Jacoby and Skoufias (2002) find that parental income is an important determinant of college attendance. Kaufmann (2014) shows that poor individuals with high expected returns are particularly responsive to changes in direct costs of college and that a sizeable fraction of poor individuals would attend college if direct costs of college attendance decreased.

Higher enrollment rates in the face of high costs of education and lack of financial support are consistent with households having increased resources to finance education. There is evidence that access to credit in Mexico increased in the decade of the 1990s. The ENIGH survey can be used to relate the change in the level of credit constraints to measurable changes in the credit market. The ENIGH has a similar structure to the Family Expenditure Survey in the UK and is available for 1984, 1989, 1992 and every two years since then. Since 1992 the ENIGH survey contains detailed information on a number of variables that can be used

to compute measures of financial income and wealth assets (Binelli and Attanasio 2010). I use the ratio of credit cards debts and consumer loans to household labour income as a proxy for the amount of borrowing over household income, and I find that this proxy increased by around 30% between 1992 and 2002.[17]

In addition to the micro-evidence provided by the ENIGH, there is also macro-evidence that in the 1990s in Mexico borrowing constraints became less stringent. Evidence from the Bank of Mexico shows that in 2002 the amount of credit to consumers was almost double the size of the amount in 1994 due to a process of financial liberalization and deregulation of the securities markets, which resulted into an increased availability of consumer credit. The most recent available data from the Bank of Mexico show that the increase in consumer credit still continues: at the end of 2008 the total amount of credit to consumers was almost three times the size of the amount granted in 2002.[18]

4.4   Labour market institutions and international migration

The model abstracts from labour market institutions such as unions and minimum wages, and international migration, which could be two potentially important determinants of the wage convexification. Minimum wages could have played a particularly important role by preventing the wages of workers with basic education to fall below a certain threshold thus contributing to the decrease in relative wages of intermediate educated workers. However, in the 1990s in Mexico the degree of unionization markedly declined (Raymundo, Esquivel, and Lustig 2012), and minimum wages decreased by around 50% relative to median earnings (Bosch and Manacorda 2010). Therefore, in the period of analysis unions lost power and minimum wages did not act as an anchor for low skilled wages by preventing wages of workers with basic education to fall.

A second potentially important factor that is not included in the model and could have affected wages by education in the decade of the 1990s is international migration. In par-

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[17]The ENIGH evidence is as follows: in 1992 the median amount of credit cards debts and consumer loans and median household labour income were, respectively, at around 551 and 8346 Mexican Pesos; in 2002 these amounts increased to, respectively, around 2073 and 5698 Mexican Pesos. Thus, the median ratio of credit cards debts and consumer loans over household labour income increased from around 6% to 36%.

[18]http://www.banxico.org.mx/estadisticas/statistics.html

ticular, in the 1990s there were vast migration flows from Mexico to the US, which could have resulted in changes in the level of wages by education and thus to the convexification. However, these migration flows were mainly outflows of low-skilled workers with two thirds of the adult Mexican immigrants to the US having not completed intermediate education.[19] This low-skilled migration could have contributed to the sustained low value of the wages of workers with basic education, but there is no evidence that it did contribute to the decline of the wages of workers with intermediate education, which drove the convexification.

5   Conclusion

This paper studies a central feature that characterizes the changes in wage inequality in the decade of the 1990s: the wage-education profile convexified. The wage differential between higher and intermediate education increased and the wage differential between intermediate and basic education declined. These wage changes have important implications for the process of human capital accumulation. The non-linearity of the wage profile changes the opportunity costs of investing in education, which becomes profitable only if college education is completed, and may induce the poor to drop out of school or even not to invest in human capital at all if they cannot afford financing education until the end of college.

In several low and middle-income countries the convexification was particularly pronounced and came together with significant changes in the demand and in the supply of educated labour. Using data from Mexico I show that the simultaneous changes in the demand and in the supply of labour were a fundamental determinant of the convexification: an initial increase in the demand for educated workers induced a supply reaction with non-linear effects on wages due to complementarities in production between workers with intermediate and with higher education. The supply reaction happened because of increased availability of borrowing that relaxed credit constraints. The finding that easier access to credit has led to an erosion of the returns to intermediate education provides further evidence of the "paradox of progress" that a more equal stock of education could increase inequality if returns to schooling are convex (Bourguignon, Ferreira and Lustig 2005 and Gasparini,

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[19]www.cis.org

Galiani, Guillermo and Acosta 2011). Effective policy interventions to promote educational investments should account and compensate for the non-linear costs of schooling at different levels of education.

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Appendix A - The ENEU and the Mexican education system

A1 The Mexican employment survey (ENEU)

The ENEU (*Encuesta Nacional de Empleo Urbano*) is the Mexican employment survey collected yearly by the Mexican national statistical office, INEGI. It is available yearly from 1987 to 2004 and it covers only urban areas with municipalities being the primary sampling units. The sampling scheme has changed over time with a number of smaller municipalities having progressively entered the sample. The ENEU is a quarterly household survey with a rotating panel structure similar to the US Current Population Survey: households are interviewed for five consecutive quarters and in each quarter 20% of the households are replaced by new households that are interviewed for the first time. The survey reports detailed employment information on individuals at least twelve years old with several questions on occupation status, type and characteristics of employment, sector of main and secondary job, contract type, working hours, monthly earnings, unemployment status and duration, and social security taxes paid by the worker's employer in the private and public sector. Importantly for the analysis in this paper, the ENEU accurately reports earnings for each individual in each of four consecutive quarters. For those paid by the week the survey transforms weekly earnings into monthly earnings by multiplying the former by 4.3. Similar adjustments are used for workers paid by the day or every two weeks. Hourly wages are computed as the ratio between monthly earnings and hours worked in the main occupation.

The definition of earnings in the survey refers to monthly earnings received from the main job net of all labour taxes and social security contributions paid in either public or private funds. The use of after-tax earnings to study the convexification could be problematic in the presence of changes in the tax system that induced an increase in after-tax wages more at the top than at the bottom of the distribution. Indeed, data show that between 1987 and 2002 top marginal tax rates in Mexico decreased from 55% to 35%.[20] However, overall, the tax changes that were implemented in Mexico as well as in most Latin American countries in the 1990s were characterized by a general decrease in net tax rate, due to very high personal exemptions and deductions, and very low taxes on capital gains and incomes from financial

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[20]http://www.taxpolicycenter.org/taxfacts/

sources, so that the progressivity of personal income taxes did barely affect the progressivity of the tax system (Tanzi 2000), with no evidence of substantial distributional effects to the top of the income distribution.

A2 The Mexican education system and the construction of the education groups

The Mexican education system consists of four main cycles: pre-school, primary, secondary, and post-secondary education. Pre-school education is between age 3 and 6 and is provided free of charge. Primary education starts at age 6, lasts 6 years and has always been compulsory. Secondary education comprises two main levels: lower and upper secondary. Lower secondary lasts between 3 to 4 years, depending on the program. Upper secondary lasts 3 years. Both levels of secondary education includes an "academic" and a "vocational" branch that paves the way, respectively, to university and non-university education. In 1993 lower secondary education became compulsory. This policy change mainly affected rural areas with a large increase in the construction of schools and corresponding increasing attainment rates at lower secondary education in these areas. Post-secondary education comprises universities, 2 and 4-years technical institutes, and graduate education. By far the majority of undergraduate students are enrolled in universities and a very small proportion is enrolled in 2-years technical institutes. University takes 4 to 5 years and graduate education lasts between 2 to 4 years.

I have aggregated the schooling levels as follows: the "basic education" group includes those with up to uncompleted upper secondary education, the "intermediate education" group includes those with up to uncompleted university education, and the "higher education" group includes those with completed university education or more. In the decade of the 1990s average attainment rates were above 90% at primary education nationwide; at lower secondary they were above 80% in urban areas and below 40% in rural areas. Since the ENEU only covers urban areas I group primary and lower secondary education into "compulsory basic education". Finally, following Manacorda, Sanchez-Paramo and Schady (2010), I combine the academic and vocational branch of secondary education by considering in the "intermediate education" group all that have completed any of the two branches.

Appendix B - Estimation and calibration

B1 Estimation
1. Wage equations

In order to estimate equation (1), I exploit the ENEU quarterly panel structure by specifying the following log wage equation for individual i with education level j in quarter qr:

$$\ln w_{j,qr}^i = \ln w_{j,qr} + g_j(age_{qr}^i) + u_{j,qr}^i \qquad j = 1,2,3 \qquad (15)$$

$$u_{j,qr}^i = \eta^i + z_{j,qr}^i \qquad (16)$$

$$z_{j,qr} \sim N(0, \sigma_{z_{j,qr}}^2) \qquad (17)$$

where $\ln w_{j,qr}^i$ is the log hourly real wage of individual i with education level j in quarter qr, $\ln w_{j,qr}$ is the average log wage among those with education level j in quarter qr, $g_j(.)$ is an education-specific quadratic polynomial in age that proxies for experience in the labour market, η^i is a permanent individual-specific effect, and z is an i.i.d. shock.

The estimates of equation (15) are used to parameterize the wages of the working population in the baseline model, that is the wages of both adult (parents) and young (children) workers in 1987. Therefore, I consider all workers aged between 15 (minimum legal working age) and 60 (average retirement age) in the ENEU survey for 1987, and I exploit the quarterly rotating panel structure of the ENEU by constructing panels of individuals by matching workers by the position in an identified household, number of years of education and age. I then run the following fixed effects regression:

$$(\ln w_{j,qr}^i - \ln \overline{w}_j^i) = (\ln w_{j,qr} - \ln \overline{w}_j) + g_j(age_{qr}^i) - g_j\overline{(age^i)} + (u_{j,qr}^i - \overline{u}_j^i) \qquad (18)$$

where the upper-bar variables denote time averages over the four quarters in a given year. $\ln \overline{w}_j^i$ is the average log wage over the four quarters for the ith individual with the jth education level, $\ln \overline{w}_j$ is the mean log wage over the four quarters for education level j. The term $(\ln w_{j,qr} - \ln \overline{w}_j)$ is modelled as quarter-education dummies' interactions. $g_j(age_{qr}^i)$ is an education-specific quadratic polynomial in age.

The estimation of equation (18) allows to measure $\widehat{\eta}_i$, the unconditional distribution of ability of the working population, as follows:

$$\widehat{\eta}_i = \frac{\sum\limits_{n=1}^{N(i)} \ln w_{qr}^i - \widehat{\ln w_{qr}} - \widehat{g(age_{qr}^i)}}{N(i)} \tag{19}$$

where $N(i)$ is the total number of observations available on individual i. I find that the distribution of $\widehat{\eta}_i$ has a variance of 0.25 and a zero mean, which I use to parameterize the ability distribution in the model.

By having estimated equation (18), I can treat as observable the following:

$$z_{j,qr}^i = \ln w_{j,qr}^i - g_j(age_{qr}^i) - \ln w_{j,qr} - \eta^i \tag{20}$$

where $z_{j,qr}$ is normally distributed with mean zero and variance $\sigma_{z_j}^2$. I find that $\widehat{\sigma}_{z1}^2 = 0.25$, $\widehat{\sigma}_{z2}^2 = 0.26$, and $\widehat{\sigma}_{z3}^2 = 0.29$, which I use to parameterize the distribution of z in the model.

I obtain an estimate of the age effects by running equation (18) for each year between 1987 and 2002 and by taking the average of the yearly rescaled estimates of the age and age squared term by education. For the linear term in age, I estimate 0.157, 0.197 and 0.256, respectively, for basic, intermediate, and higher education; the corresponding estimates for the quadratic term in age are: -0.018, -0.015, and -0.022. These estimates are consistent with standard estimates of concave returns to experience increasing by level of education.[21]

2. Production function

The method used to approximate the aggregate human capital series follows Heckman, Lochner and Taber (1998) by obtaining the estimated value of human capital j at time t, $\widehat{H}_{j,t}$, as the ratio of the total wage bill for education level j in year t, and an estimate of the price for that level of education in that year, $\widehat{p}_{j,t}$.

I obtain an estimate of the log prices by level of education and year by running the

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[21]Since each model's period is equal to 7 years, the age effects can equivalently be estimated by constructing seven years age cohorts and using the pooled 1987-2002 dataset to estimate a cohort wage regression where wages for individual i in year t depend on a constant term, education level interacted with cohort and cohort squared, and education-year interaction terms.

fixed effect regression specified in equation (18) for each year between 1987 and 2002 and by computing the predicted mean log hourly real wage by level of education net of the individual fixed effects η_i. In order to compute the wage bills I use the Mexican Expenditure Survey, the ENIGH, that is nationally-representative and reports individual earnings together with detailed information on assets and consumption. The ENIGH is available in 1984, 1987 and every two years since then.

For each year between 1987 and 2002 and education group I compute the wage bill by summing over the individual earnings of all primary wage earners aged between 15 and 60. I linearly interpolate the available data for the missing years. Given the wage bills and the (log) education prices, I can divide the wage bills by the exponentiated value of the log price of education to obtain the time series of the human capital aggregates for each year and education group. The identification of the H factors is then consistent with the ability distribution estimated from the data and used to simulate the model. Log linearizing the relative price of higher and intermediate education, $\frac{p_{3,t}}{p_{2,t}} = \frac{\alpha_{3,t}}{(1-\alpha_{3,t})}\left(\frac{H_{3,t}}{H_{2,t}}\right)^{\theta-1}$, and rewriting it in terms of wage bills, I obtain:

$$(\log WB_{3,t} - \log WB_{2,t}) = [\log \alpha_{3,t} - \log(1 - \alpha_{3,t})] + \theta(\log \widehat{H}_{3,t} - \log \widehat{H}_{2,t}) \qquad (21)$$

where $\widehat{H}_{3,t}$ and $\widehat{H}_{2,t}$ denote the estimated higher and intermediate human capital aggregate at time t. The time-varying factor shares $\alpha_{2,t}$ and $\alpha_{3,t}$ reflect changes in the productivity of and in the demand for workers with intermediate and higher education. I express the log of the share parameters as the sum of a constant and a time-varying component:

$$\log \alpha_{j,t} = \phi_{0,j} + \phi_{1,j} * t + e_{j,t} \qquad (22)$$

where $\phi_{0,j}$ is an education-specific constant, t denotes a linear time trend and $e_{j,t}$ is a normally distributed i.i.d. shock at time t for education level j.

Combining equation (21) and (22), I estimate the value of the parameter determining the elasticity of substitution between higher and intermediate education, θ, from a regression of the ratio of the log wage bills on the ratio of the human capital aggregates, a linear trend and a constant. Then, I construct a measure of skilled human capital as a weighted sum

of workers with intermediate and higher education. To do so, I need an estimate of the log factor shares $\alpha_{3,t}$. Given equation (21) and (22) and the fact that $\alpha_{2,t} = (1 - \alpha_{3,t})$, I have that $\log\left[\frac{\alpha_{3,t}}{(1-\alpha_{3,t})}\right] = (\beta_0 + \beta_1 * t)$, where $\beta_0 = (\phi_{0,3} - \phi_{0,2})$ and $\beta_1 = (\phi_{1,3} - \phi_{1,2})$. Therefore, $\alpha_{3,t} = \frac{\exp(\beta_0 + \beta_1 * t)}{(1 + \exp(\beta_0 + \beta_1 * t))}$. Finally, I can estimate a regression of the ratio of the log wage bills for skilled and unskilled on the ratio of skilled and unskilled human capital, a linear trend and a constant to obtain an estimate of ρ. Using the wage bill equations for skilled and unskilled, the equivalent of equation (22) for $\log \delta_{s,t}$ and the definition of the unskilled labor share as one minus the skilled share, I can identify $\delta_{s,t}$ following the same steps used to identify $\alpha_{3,t}$. For the year 1987, I obtain a baseline estimate of 0.55 for α_3 and of 0.69 for δ_s.

Equation (21) suffers from endogeneity: changes in the relative supply of education react to the changes in relative demand that this equation is set to identify. I instrument $(\log \widehat{H}_{3,t} - \log \widehat{H}_{2,t})$ with the lagged values of $(\log \widehat{H}_{3,t} - \log \widehat{H}_{2,t})$ and with the size of the cohorts of workers with compulsory basic education measured as the proportion of those with primary education in a given year. The first instrument is a standard instrumental variable often used in macroeconomics to estimate production functions (e.g. Heckman, Lochner and Taber, 1998; Gallipoli, Meghir and Violante 2008). The assumption is that lagged relative supply impacts on relative wages only via current relative supply, the validity of which increases with longer time series. With sixteen years of data (1987-2002) I can experiment with the use of different sets of lags. The second instrument is motivated by the very nature of the model: primary education is compulsory so it is not a margin of choice. At the same time, it impacts on educational investments at both intermediate and at higher education by determining the level of the price of basic education and therefore the relative returns to intermediate as well as to higher education.

Table 9 reports the estimates of the elasticity of substitution between higher and intermediate education: the first, second and third column report, respectively, the second-stage and the first-stage results when using as instrumental variable the first lag of the log human capital difference (IVa), the size of the cohorts of workers with primary education (IVb), and both of them (IVc, where the first row of the first-stage results reports the estimates obtained when I use as instrument the first lag of the log human capital difference, and the second row reports the estimates obtained when I use as instrument the size of the cohorts

of workers with primary education). Table 10 reports the estimates of the elasticity of substitution between skilled and unskilled: the second-stage results, and the first-stage results when using as instrument the first lag of the log human capital difference.[22] All instruments in the first stage have a strong significant impact on the endogenous variable and in the expected direction.

	Higher versus Intermediate		
Parameter	IVa	IVb	IVc
Difference log H	0.7726	0.7331	0.7239
	(0.0636)	(0.0556)	(0.0583)
Time trend	0.0262	0.0279	0.0287
	(0.0048)	(0.0041)	(0.0049)
Constant	−51.9469	−55.2268	−56.8015
	(9.5317)	(8.2465)	(9.7303)
Implied ES	4.4	3.7	3.6
	First Stage		
Instruments' set	0.5796	−6.4816	0.2184
	(0.1822)	(1.5061)	(0.1753)
			−6.2105
			(2.3588)

Table 8: Estimation of the production function: IV regression of the ratio of log wage bills for higher and intermediate on the ratio of human capitals, a linear trend and a constant. IVa: instrument is first lagged difference of higher and intermediate human capital. IVb: instrument is the size of the primary educated cohort. IVc: instruments are both first lagged difference of higher and intermediate human capital and size of the primary educated cohort. Standard errors in parenthesis.

There are two sets of important parameters' estimates in Tables 9 and 10: the time trends and the implied elasticity of substitution (ES). The time trends' estimates mean that between 1987 and 2002 the demand for higher educated and for skilled workers increased, respectively, by around 2.7% and 1.35% a year. The ES between workers with higher and with intermediate education ($\frac{1}{1-\widehat{\rho}}$) is lower than the ES between workers with either higher (or intermediate) and with basic education, which is consistent with the presence of complementarities in production between workers with intermediate and with higher education.

I assess the robustness of the estimation results by running two specification tests. First, I

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[22]The size of the primary educated cohorts is not valid in this case since it is a linear function of the denominator of the endogenous variable to be instrumented.

Parameter	Skilled versus Unskilled
Difference log H	0.8601
	(0.1362)
Time trend	0.0135
	(0.0065)
Constant	−26.0616
	(13.0620)
Implied ES	7.1
	First Stage
Lagged difference log H	0.8327
	(0.1512)

Table 9: Estimation of the production function: IV regression of the ratio of log wage bills for skilled and unskilled on the ratio of human capitals, a linear trend and a constant. Instrument is first lagged difference of skilled and unskilled human capital. Standard errors in parenthesis. "Unskilled" are workers with basic education. "Skilled" is the sum of workers with intermediate and with higher education.

run a joint estimation of the system of equations used to estimate the elasticity of substitution of higher versus intermediate and of skilled versus unskilled, that is the system of equations made by the IV regression of equation (21) and the IV regression of the equivalent equation for skilled and unskilled, in order to test for the equality of the coefficients of the log relative supply of higher and intermediate and skilled and unskilled labour: the test gives a value of chi-squared of 7.1 with a P-value of 0.0077 confirming that ρ and θ are statistically significantly different. Second, a test for the assumption of equality between $ES_{3,1}$ and $ES_{2,1}$, which is a restriction imposed by the symmetry of the CES operator: the test returns a value of chi-squared of 0.35 with a P-value of 0.5525, therefore failing to reject the null hypothesis of equal coefficients.

B2 Calibration

1. Initial distribution of wealth and education, costs of schooling, and preferences

The ENIGH survey provides individual data on wealth and consumption. I set the initial wealth distribution to a lognormal distribution with mean and standard deviation computed from the distribution of financial assets of the workers aged between 25 and 60 in the ENIGH

survey for 1992. I find the mean and standard deviation to be, respectively, 0.25 and 0.71.[23] I set the initial distribution of education of the adult and the young population to match the education distributions observed in the 1987 ENEU data. Consistently with the OLG model's assumptions, I define the "adult workers' population" in the ENEU as the one made by all working heads of households aged between 25 and 60 with basic, intermediate and higher education, and the "young workers' population" as the one made by all workers living with their parents, aged between 15 and 24, and that have completed basic and intermediate education. I compute the education distribution of the adult workers as the relative proportions of adult workers with basic, intermediate and higher education in 1987, and the education distribution of the young workers as the relative proportion of those with basic and intermediate education among the young.

The fixed costs of schooling by level of education are set to match the education distribution of the adult in the ENEU 1987. I find that $F_1 = 0.035$, $F_2 = 0.26$ and $F_3 = 0.64$, which implies that the costs of intermediate education are around seven times the costs of basic education and the costs of higher education are around eighteen times the costs of basic education. The F_j fixed costs in the model measure the average total direct costs of education, which include fees, costs of school material and maintenance. An empirical counterpart of these costs is provided by the first wave of the Mexican Family Life Survey (MxFLS), which collects high quality data on a rich set of variables for a cross section of Mexican households in 2002. The MxFLS contains a detailed set of questions on education costs and distinguishes between tuition fees, costs of exams, books, school material, uniforms and maintenance costs for public and private schools. Summing over all these different costs' categories and averaging the costs over public and private education, I find that the costs of intermediate education are around eight times the ones at primary while the costs at higher education are around nineteen times the ones at primary, which is remarkably close to the relative magnitudes obtained from the model's calibration. The model abstracts from non-pecuniary or indirect costs of education. Despite being informative for policy inference (e.g. Heckman, Lochner and Taber 1998), the distinction between direct and indirect costs

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[23]I parameterize the wealth distribution using the moments of the 1992 ENIGH survey since the ENIGH reached its final structure only in 1992 with significant changes in the questionnaire and data collection in the years before.

of schooling is not key to the arguments developed in this paper.

The coefficient of relative risk aversion, γ, is set to 0.9 that gives a value of around 1.1 for the elasticity of intertemporal substitution (EIS), which falls within the estimated value of the EIS provided by Arrau and van Wijnbergen (1991) for Mexico. Consumption is adjusted to account for the presence of the child. I use an equivalence scale of 0.7 for a child, which reflects the average calories intake of a child relative to an adult as reported by the Mexican National Nutritional Institute (Hernández, Chávez and Bourges, 1987). Assuming that parent-child dynasties are linked by fully altruistic preferences, I set the altruism parameter, λ, to one. I set the limit on net indebtedness, B, to zero, which corresponds to the maximum level of credit constraints.

2. Interest rate and capital share

Mexico can be characterized as a small economy open to financial trade, particularly with the US. Consistently, I set the value of the real interest rate, r, to a 5% US benchmark value, which is the average real interest rate on the US 6-months Treasury Bills published by the Federal Reserve Board for the period between 1990 and 2000. Given an average working life of the adult Mexican population of approximately thirty years, the model period is set to 7 years. Therefore, the interest rate in the model is $r = (1.05^7 - 1) \cong 0.41$. Setting the yearly discount factor equal to the inverse of $(1 + r)$, $\beta = 1.05^{-7} \cong 0.71$. The capital share, α, is set to 0.35, which is the average value between the lower and the upper bound estimate for Latin American countries (Bosworth 1998 for a discussion of the empirical issues involved in the estimation of the capital share in Mexico, and Harrison 1996, and Hoffman 1993 for two cross-countries empirical studies that use a capital share that varies between the value of 0.3 and 0.4 for a group of Latin American countries).