Fiscal Studies (1999) vol. 20, no. 1, pp. 25–40

Human Capital Formation and General Equilibrium Treatment Effects: A Study of Tax and Tuition Policy

JAMES J. HECKMAN, LANCE LOCHNER and CHRISTOPHER TABER*

Abstract

Policies to promote human capital formation have been advocated as a remedy for reducing the economy-wide problem of rising wage inequality. These policies are national in character and are designed to substantially alter the proportion of the work-force that is skilled. Yet the methods used to evaluate these policies are partial equilibrium in nature and do not take account of the consequences of the changes in skill prices that are produced by the policies.

This paper summarises our research on general equilibrium evaluation of tuition and tax policies. We compare estimates of policy impact from our approach with those obtained from conventional partial equilibrium 'treatment effect' approaches to policy evaluation, and find substantial differences. Conventional partial equilibrium approaches present an overly optimistic view of what tax and tuition policy can achieve because they ignore the change in human capital investment levels induced by the change in prices due to the policy. In addition, conventional partial equilibrium approaches fail to provide an accurate assessment of the welfare consequences of these policies.

JEL classification: H2, I2.

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*Heckman is in the Department of Economics at the University of Chicago; Lochner is in the Department of Economics at the University of Rochester; Taber is in the Department of Economics at Northwestern University.

This research was supported by grant from the Russell Sage Foundation and NSF-SBR-97-09-873. The authors thank Lars Hansen and Alice Nakamura for helpful comments. This paper combines and extends material from two other papers — 'General equilibrium treatment effects: a study of tuition policy' and 'Tax policy and human capital formation', published in 1998 in *American Economic Review*, vol. 88, no. 2.

I. INTRODUCTION

The new labour market for skills has witnessed a shift in demand in favour of skilled labour at the expense of unskilled labour. Many economists and policymakers have called for expansion of public programmes promoting human capital formation to reverse this trend. The logic of these proposals is simple. By making the work-force more skilled, more people will benefit from the new labour market for skills, and the growth in the wages of the skilled will be dampened. The unskilled will become scarcer, thereby attenuating the downward drift in their real wages.

Most of the recent policy proposals extrapolate well outside the range of known experience. Microeconomic evaluations of these policies typically ignore the effects of changes in skill quantities on skill prices. Yet most policy proposals are national in character and are expected to change skill prices. Indeed, this is one rationale for their adoption.

This paper is a progress report on our ongoing research on formulating and estimating dynamic general equilibrium models with endogenous human capital accumulation that can be used to evaluate national skill policies. We consider two policies in particular: tax reforms and tuition subsidies.

Missing from recent discussions of tax reform is any systematic discussion of the effects of taxes on skill formation (see the papers in the collection edited by Aaron and Gale (1996)). This gap in the empirical literature in public finance is due to the absence of any empirically based general equilibrium models with both human capital formation and physical capital formation that are consistent with observations on modern labour markets. Missing from the labour economics literature that examines the impact of tuition on university attendance is any account of the effect of a wide-scale reduction of tuition on skill prices. The microeconometric 'treatment effect' literature is partial equilibrium in character and ignores the consequences of the policies studied on skill prices and any feedback effects on supply decisions.

To improve on current practice, we have developed a dynamic overlapping-generations general equilibrium framework for the pricing of heterogeneous skills based on an empirically grounded theory of the supply of education and post-education human capital (on-the-job training), where different education levels represent different skills. Individuals differ in learning ability and in initial endowments of human capital. Household saving behaviour generates the aggregate capital stock, and output is produced by combining the stocks of different types of human capital with physical capital. Our model explains the pattern of rising wage inequality experienced in the US in the past 30 years (Heckman, Lochner and Taber, 1998).

In this paper, we use our model to study the impacts on skill formation of proposals to switch from progressive taxes to flat income and consumption taxes. For the sake of brevity, we focus on steady states, although we study both transitions and steady states in other research (see Heckman, Lochner and Taber (1998 and 1999)). In the absence of labour supply responses and direct pecuniary or non-pecuniary costs of human capital investment, there is no effect of a proportional wage tax on human capital accumulation. Both marginal returns and costs are scaled down in the same proportion. When untaxed costs or returns to education are added to the model (i.e. non-pecuniary costs or benefits), proportional taxation is no longer neutral. An increase in the tax rate decreases university attendance if the net financial benefit before taxes is positive. Progressivity reinforces this effect. A progressive wage tax reduces the incentive to accumulate skills, since human capital promotes earnings growth and moves people to higher tax brackets. As a result, marginal returns on future earnings are reduced more than marginal costs of education.

Heckman (1976) notes that, in a partial equilibrium model, proportional taxation of interest income with full deductibility of all borrowing costs reduces the after-tax interest rate and, hence, promotes human capital accumulation. In a time-separable, representative-agent general equilibrium model, the after-tax interest rate is unaffected by the tax policy in the steady state as agents shift to human capital from physical capital (see Trostel (1993)). In that framework, flat taxes with full deductibility have no effect on human capital investment. In a dynamic overlapping-generations model with heterogeneous agents and endogenous skill formation and with progressive rates, taxes have ambiguous effects on human capital and both their quantitative and qualitative effects can only be resolved by empirical research.

The paper also considers the effects of changes in tuition fees on university education and earnings, accounting for general equilibrium effects on skill prices. The typical evaluation estimates the response of university enrolment to variation in tuition fees using geographically dispersed cross-sections of individuals facing different tuition rates. These estimates are then used to determine how subsidies to tuition fees will raise enrolment. The estimated impact of tuition policies on earnings is evaluated using an education–earnings relationship fit on pre-intervention data and does not account for the enrolment effects of the taxes raised to finance the tuition subsidy. Kane (1994) exemplifies this approach.

The danger in this widely used practice is that what is true for policies affecting a small number of individuals need not be true for policies that affect the economy at large. A national tuition fee reduction policy that stimulates substantial university enrolment is likely to reduce skill prices, as advocates of the policy claim. However, agents who account for these changes will not enrol in university at the levels calculated from conventional procedures, which ignore the impact of the induced enrolment on earnings. As a result, standard policy evaluation practices are likely to be misleading about the effects of tuition policy on university attainment and wage inequality. The empirical question is 'how misleading?'. We show that these practices lead to estimates of enrolment responses that are more than 10 times larger than the long-run general equilibrium effects. We also improve on current practice in the 'treatment effects' literature by considering both the gross benefits of the programme and the tax costs of financing the 'treatment' as borne by different groups. Evaluating the general equilibrium effects of a national tuition fee policy requires more information than the tuition-enrolment parameter that is the centrepiece of partial equilibrium policy analysis.

The statistical and econometric literature on 'treatment effects' is remarkable for its inattention to the market consequences of the programmes it evaluates. The widely used 'Rubin' model (Rubin, 1978) assumes no interactions among the agents being analysed. The paradigm in the econometric literature on 'treatment effects' is that of evaluating the effectiveness of a drug. It assumes that there are no spillovers to society at large that flow from drug use (or 'treatment') by individuals. The literature in economics recognises these spillover effects. The classical analysis of union relative wage effects by Lewis (1963) explicitly accounts for the discrepancy between the effects of 'treatment' (unionism) on an individual and 'treatment' applied to an industry when prices adjust to industry-wide unionisation levels. Our analysis extends Lewis's static general equilibrium framework to a dynamic setting with skill formation.

II. CONVENTIONAL MODELS OF 'TREATMENT EFFECTS'

The standard framework for microeconometric programme evaluation is partial equilibrium in character (see Heckman and Robb (1985)). For a given individual i, $Y_{1,i}$ is defined to be the outcome the individual receives if he participates in the programme and $Y_{0,i}$ is the outcome he receives if he does not participate. The 'treatment effect' for person i is $\Delta_i = Y_{1,i} - Y_{0,i}$. When interventions have general equilibrium consequences, these effects depend on who else is 'treated' and the market interaction between the 'treated' and the 'untreated'.

To see the problems that arise in the standard framework, consider instituting a national tuition fee policy. In this case, $Y_{0,i}$ is person i's wage if he does not attend university and $Y_{1,i}$ is his wage if he does attend. The 'parameter' Δ_i then represents the impact of university, and it can be used to estimate the impact of tuition policies on wages. It is a constant, or policy-invariant, parameter only if wages ($Y_{0,i}$ and $Y_{1,i}$) are invariant to the number of university and high-school graduates in the economy or happen to move in exactly the same way in all states of the economy.

In a general equilibrium setting, a decrease in tuition fees increases the number of individuals who attend university, which in turn decreases the relative wages of university attendees, $Y_{1,i}/Y_{0,i}$. In this case, the programme not only affects the wages of individuals who are induced to move by the programme, but it also has an impact on the wages of those who do not move. For two reasons, then, the 'treatment effect' framework is inadequate. First, the parameters of interest depend on who in the economy is 'treated' and who is not. Second, these parameters do not measure the full impact of the programme. For example, increasing tuition subsidies may increase the earnings of uneducated individuals who do not take advantage of the subsidy. To pay for the subsidy, the highly educated would be taxed and this may affect their investment behaviour. In addition, more competitors for educated workers enter the market as a result of the policy, and their earnings are depressed. Conventional methods ignore the effect of the policy on non-participants. In order to account for these effects, it is necessary to conduct a general equilibrium analysis.

III. OUR MODEL

Our analysis builds on the model of Auerbach and Kotlikoff (1987) in two ways: (1) we introduce skill formation and consider both choice of educational level and investment in on-the-job training; and (2) we allow for heterogeneity in ability, endowments and skills. Different education levels are associated with different skills and different post-school investment functions. We relax their efficiency-units assumption for labour services. Models with efficiency units for labour services do not explain rising wage inequality among skill groups. Our model has three sources of heterogeneity among persons: (1) in age; (2) in ability to learn and in initial endowments; and (3) in the economic histories experienced by cohorts. In a transition period, different cohorts face different skill prices, make different investment decisions and, hence, accumulate different amounts of human capital and have different wage levels and trajectories. Our model extends the analysis of Davies and Whalley (1991), who introduce human capital into the Auerbach–Kotlikoff model but assume only one skill. We allow for multiple skills, incorporate both education and on-the-job training, and allow for rational expectations in calculating transition paths.

In our model, individuals live for $\overline{a}$ years and retire after $a_R < \overline{a}$ years. In the first stage of the life cycle, a prospective student chooses the schooling option that gives him the highest level of lifetime utility. Define K_{at} as the stock of physical capital held at time t by a person aged a; H^S_{at} is the stock of human capital at time t of type S at age a. The optimal life-cycle problem can be solved in two stages. First, condition on education and solve for the optimal path of consumption (C_{at}) and post-school investment time (I_{at}^{S}) for each schooling level. Second, select among education levels to maximise lifetime welfare.

Given S, an individual aged a at time t has the value function

$$(1) \quad V_{at}\left(H_{at}^{S}, K_{at}, S\right) = \max_{C_{at}, I_{at}^{S}} \frac{C_{at}{}^{\gamma} - 1}{\gamma} + \delta V_{a+1,t+1}\left(H_{a+1,t+1}^{S}, K_{a+1,t+1}, S\right)$$

where δ is a time preference discount factor, γ (<1) is a preference parameter governing the marginal utility of consumption and $\frac{1}{\gamma - 1}$ is the elasticity of intertemporal substitution (eis). We follow Kotlikoff, Smetters and Walliser (1997) — henceforth KSW — by assuming that the tax schedule can be approximated by a progressive tax on labour income and a flat tax on capital income. This gives a dynamic budget constraint

$$(2) \quad K_{a+1,t+1} \leq K_{at}\left(1 + (1 - \tau_k) r_t\right) + R_t^S H_{at}^{S}\left(1 - I_{at}^{S}\right) - \tau_{\ell}\left(R_t^S H_{at}^{S}\left(1 - I_{at}^{S}\right)\right) - C_{at}$$

where τ_k is the proportional tax rate on capital, τ_{ℓ} is the progressive tax schedule on labour earnings, R_t^S is the price of human capital services of type S at time t, and r_t is the net return on physical capital at time t. We have experimented with other progressive tax schedules and obtain results similar to the ones we report here. In this paper, we abstract from labour supply. Estimates of intertemporal substitution in labour supply estimated on annual data are small, so ignoring labour supply does not affect our analysis. This simplification makes our model comparable to that of Davies and Whalley, who also ignore leisure. On-the-job human capital for a person of schooling level S accumulates through human capital production function

$$(3) \quad H_{a+1,t+1}^{S} = A^{S}(\theta) I_{at}^{\alpha_S} H_{at}^{\beta_S} + \left(1 - \sigma^{S}\right) H_{at}^{S}$$

where the conditions $0 < \alpha_S < 1$ and $0 < \beta_S < 1$ guarantee that the problem is concave, σ^S is the rate of depreciation of skill-S-specific human capital, θ denotes an ability type, α_S (<1) governs the marginal productivity of investment time, β_S governs the self-productivity of capital and $A^S(\theta)$ is the efficiency factor by which agents transform investment time and the current human capital stock into increments of human capital. This functional form is widely used in both the empirical literature and the literature on human capital accumulation. The α and β are also permitted to be *S*-specific, which emphasises that education affects the process of learning on the job in a variety of different ways.

Notably absent from our model are the short-run credit constraints that are often featured in the literature on education and human capital accumulation. Our model is consistent with the evidence presented in Cameron and Heckman (1998 and 1999) that long-run family factors correlated with income (the θ operating through $A^S(\theta)$ and the initial condition of *H* for (3)) affect education, but that short-term credit constraints are not empirically important. Such long-run factors account for the empirically well-known correlation between educational attainment and family income.

At the beginning of life, agents choose the value of *S* that maximises lifetime utility:

$$\hat{S} = \underset{S}{\arg\max}\left[V^S(\theta) - D^S + \varepsilon^S\right] \tag{4}$$

where $V^S(\theta)$ is the tax-adjusted present value of earnings at education level *S* computed from the optimal programme, D^S is the discounted tuition cost of schooling and ε^S represents non-pecuniary benefits expressed in present value terms.

Tuition costs are permitted to change over time so that different cohorts face different education costs. The economy is assumed to be competitive so that the prices of skills and capital services are determined as the marginal products of an aggregate production function. In order to compute service flow prices for capital and the different types of human capital, it is necessary to construct aggregates for each of the factors over each of the ability types and over all cohorts to insert into an aggregate production function.

Human capital of type *S* is a perfect substitute for any other human capital of the same educational level, whatever the age or experience of the agent, but it is not perfectly substitutable with human capital from other education levels. In our model, cohorts differ from each other only because they face different price paths and policy environments within their lifetimes.

Our aggregate production function exhibits constant returns to scale. The equilibrium conditions require that marginal products equal pre-tax prices. In the two-skill economy we analyse, the production function at time *t* is defined over the inputs $\overline{H}_t^1$, $\overline{H}_t^2$ and $\overline{K}_t$, where $\overline{H}_t^1$ and $\overline{H}_t^2$ are aggregates of utilised skills (high school and university, respectively) supplied to production and $\overline{K}_t$ is the aggregate stock of capital. The technology we use is

$$F\left(\overline{H}_t^1, \overline{H}_t^2, \overline{K}_t\right) = a_3\left(a_2\left(a_1\left(\overline{H}_t^1\right)^{\rho_1} + (1-a_1)\left(\overline{H}_t^2\right)^{\rho_1} \right)^{\rho_2/\rho_1} + (1-a_2)\overline{K}_t^{\rho_2} \right)^{1/\rho_2}.$$

We estimate that $\rho_2 = 0$ but $\rho_1 = 0.693$, which yields an elasticity of substitution between high-school and university human capital of 1.441.

Human capital accumulation functions (3) are estimated using micro-data assuming that taxes are proportional. However, an extensive sensitivity analysis reveals that, within the range of the data for the US economy, misspecification of the tax system does not affect parameter estimates if the model is recalibrated on aggregate data. We now use the model to investigate tax policies.

IV. ANALYSING TWO TAX REFORMS

Following KSW, we assume that the US income tax can be captured by a progressive tax on labour income and a flat tax on capital income. Each earner has 1.22 children and is single. For each additional dollar beyond \$9,660, there is an increase in itemised deductions of 7.55 cents. An individual with labour income Y has taxable income $(Y - 9660)(1 - 0.0755)$. Using the 1995 tax schedule, we compute the taxes paid by income and approximate this schedule by a second-order polynomial. We assume a 0.15 flat tax rate on physical capital.

We consider two revenue-neutral tax reforms from this bench-mark progressive schedule. The first reform (which we call 'Flat Tax') is a revenue-neutral flattening of the tax on labour earnings holding the initial flat tax on capital income constant. The second reform ('Flat Consumption Tax') is a uniform flat tax on consumption. In both flat-tax schemes, tuition fees are not treated as deductible. (Allowing for deductibility at US rates barely affects our estimated results.) For each tax, we consider two models: (1) a partial equilibrium model in which skill prices and interest rates are fixed; and (2) a closed economy general equilibrium model where skill prices and interest rates adjust.

Table 1 presents both partial equilibrium and general equilibrium results measured relative to a bench-mark economy with the KSW tax schedule. We first discuss the partial equilibrium effects of a move to a Flat Tax, which eliminates progressivity in wages and stimulates skill formation. University attendance rises dramatically as the higher earnings associated with university graduation are no longer taxed away at higher rates. The amount of post-education on-the-job training also increases for each skill group (as measured by the stocks of human capital per worker of each skill). The aggregate stock of high-school human capital declines, while the aggregate stock of university human capital increases as a result of the rise in university enrolment. The university–high-school wage differential (at 10 years of work experience) increases slightly, as does another widely used measure of inequality — the standard deviation of log wages. The effects of reform on aggregates of consumption and output are modest at best. However, capital formation is greatly

TABLE 1

Comparison of Steady States under Alternative Tax Regimes: Percentage Difference from Progressive Case[a]

Per cent

	Flat Tax[b]		Flat Consumption Tax[c]	
	Partial equilibrium	*General equilibrium*	*Partial equilibrium*	*General equilibrium*
After-tax interest rate	0.00	1.96	17.65	3.31
Interest rate	0.00	1.96	0.00	−12.18
Skill price, university human capital	0.00	−1.31	0.00	3.38
Skill price, high-school human capital	0.00	−0.01	0.00	4.65
Stock of physical capital	−15.07	−0.79	86.50	19.55
Stock of university human capital	22.41	2.82	−15.77	1.85
Stock of high-school human capital	−9.94	0.90	1.88	0.08
Stock of university human capital per university graduate	3.04	2.55	−4.08	1.72
Stock of high-school human capital per high-school graduate	1.84	1.07	−5.23	0.16
Fraction attending university	18.79	0.26	−12.18	0.13
Aggregate output	−0.09	1.15	15.76	4.98
Aggregate consumption	−0.08	0.16	7.60	3.66
Mean wage, university	3.39	2.60	0.12	6.96
Mean wage, high school	2.44	2.44	0.25	6.82
Standard deviation of log wage	4.09	1.56	−1.94	0.69
University–high-school wage premium at 10 years of work experience[d]	1.92	−0.45	3.10	0.18

[a]In the progressive case, we allow for a progressive tax on labour earnings but assume a 15 per cent flat tax on capital.

[b]In the Flat-Tax regime, we hold the tax on capital fixed at 15 per cent but assume that the tax on labour income is flat. Balancing the budget yields a tax rate on labour income of 7.7 per cent.

[c]In the Flat-Consumption-Tax reform, only consumption is taxed, at 10 per cent.

[d]The university–high-school wage premium measures the difference in mean log wage rates between university graduates and high-school graduates with 10 years of work experience.

reduced as the tax code now favours human capital compared with the benchmark economy.

In general equilibrium, the effects of the reform on skill formation are generally qualitatively similar, but they are greatly diminished. The effects on aggregate consumption and output are weak, as they are in the partial equilibrium case. Furthermore, the negative effects of the reform on physical capital are muted, since the return to capital increases. The rise in the after-tax interest rate chokes off skill investment. Per capita post-education on-the-job training accumulation still increases for both skill groups, although the increase is dampened compared with the partial equilibrium case. Aggregate stocks of both high-school and university human capital now rise, since university enrolment increases much less. The distinction between partial equilibrium and general equilibrium is especially striking for the fraction attending university. Though not shown in the table, university attendance increases only for the most able, whereas in the partial equilibrium case, it increases for all ability groups. In general equilibrium, changes in skill prices and interest rates virtually offset the removal of the disincentives of progressive taxes on education enrolment. The university–high-school wage differential now declines slightly. In general equilibrium, the increase in the standard deviation of log wages is smaller, because skill prices adjust and because higher after-tax interest rates flatten wage profiles.

Next, consider a move to a Flat Consumption Tax. This reform is more pro-capital and is less favourable to human capital. It raises output, capital and consumption more than a Flat-Tax reform, and it reduces the aggregate stock of high-skill human capital and the stock of human capital per worker for each skill group. The fraction attending university declines. The reform raises wage inequality as measured by the university–high-school wage premium but lowers it as measured by the standard deviation of log wages.

In general equilibrium, this reform is slightly less favourable to human capital formation than the Flat Tax, since the after-tax rate of return on capital rises more. University attendance increases slightly, but the increase is concentrated among the least- and most-able. Wage inequality increases slightly by both conventional measures. Real wages rise for both skill groups, the effect being greater than in the Flat-Tax reform. This is due to a larger increase in capital under proportional consumption taxation. Since capital is a direct complement with both forms of human capital, the increase in capital raises skill prices about the same for both skill groups. The greater increase in real wages in this case is not due to a larger increase in per capita human capital accumulation within skill groups.

V. EXPLORING INCREASES IN TUITION SUBSIDIES

Our model can also be used to evaluate proposals to subsidise tuition. We first simulate the effects of a revenue-neutral \$500 increase in tuition subsidy financed by a proportional tax on enrolment in university and wage inequality starting from a baseline economy that describes the US in the mid-1980s and that produces wage-growth profiles and education enrolment and capital stock data that match micro- and macro-statistics. The partial equilibrium increase in university attendance is 5.3 per cent in the new steady state. This analysis holds skill prices, and therefore university and high-school wage rates, fixed — a typical assumption in microeconomic 'treatment effect' analyses.

When the policy is evaluated in a general equilibrium setting, the estimated effect falls to 0.46 per cent. Because the university–high-school wage ratio falls as more individuals attend university, the returns to university are less than when the wage ratio is held fixed. Rational agents understand this effect of the tuition policy on skill prices and adjust their university-going behaviour accordingly. Policy analysis of the type offered in the 'treatment effect' literature ignores the responses of rational agents to the policies being evaluated. There is substantial attenuation of the effects of tuition policy on capital and the stocks of the different skills in our model. In our baseline specification, we allow skill prices and interest rates to adjust in general equilibrium but hold the pre-subsidy tuition level fixed. Simulating the policy under a number of additional alternative assumptions about the parameters of the economic model, including a case where tuition costs rise with enrolment, reproduces the basic result of substantial partial equilibrium effects and much weaker general equilibrium effects.

Our steady-state results are long-run effects. When we simulate the model with rational expectations, the short-run enrolment effects are also very small, as agents anticipate the effects of the policy on skill prices and calculate that there is little gain from attending university at higher rates. If we simulate using myopic expectations, the short-run enrolment effects are much closer to the estimated partial equilibrium effects. All of these results are qualitatively robust to the choice of different tax schedules. Progressive tax schedules choke off skill investment and lead to lower enrolment responses in general equilibrium.

We next consider the impact of a policy change on discounted earnings and utility. We decompose the total effects into benefits and costs, including tax costs for each group. For the sake of brevity, we report overall results and not the results by ability type. Table 2 compares outcomes in two steady states: (1) the bench-mark steady state; and (2) the steady state associated with the new tuition fees policy. Given that the estimated response to a \$500 subsidy is small, we instead use an extremely high \$5,000 subsidy for the purpose of exploring general equilibrium effects. The row 'High school – high school' reports the change in a variety of outcome measures for those persons who would be in high school under both the bench-mark and the new policy regimes; the 'High school

TABLE 2

Simulated Effects of $5,000 Tuition Subsidy on Different Groups: Steady-State Changes in Present Value of Lifetime Earnings

Thousands of 1995 dollars

Group[a] *(proportion)*	*After-tax earnings using base tax (1)*[b]	*After-tax earnings (2)*[b]	*After-tax earnings net of tuition (3)*[b]	*Utility (4)*[b]
High school – high school (0.528)	9.512	–0.024	–0.024	–0.024
High school – university (0.025)	–4.231	–13.446	1.529	1.411
University – high school (0.003)	–46.711	–57.139	–53.019	–0.879
University – university (0.444)	–7.654	–18.204	0.420	0.420

[a]The groups denote counterfactual groups. For example, the 'high school – high school' group consists of individuals who would not attend university in either steady state, and the 'high school – university' group would not attend university in the first steady state but would in the second, etc.

[b]Column 1 reports the after-tax present value of earnings in thousands of dollars discounted using the after-tax interest rate where the tax rate used for the second steady state is the base tax rate. Column 1 reports just the effect on earnings, column 2 adds the effect of taxes, column 3 adds the effect of tuition subsidies and column 4 includes the non-pecuniary costs of university expressed in thousands of 1995 dollars.

– university' row reports the change in the same measures for high-school students in the bench-mark who are induced to attend university only by the new policy; 'University – high school' outcomes refer to those persons in university in the bench-mark economy who only attend high school after the new policy is put in place; and so forth.

By the measure of the present value of lifetime earnings, some of those induced to change are worse off. Contrary to the monotonicity — or one-way-flow — assumption built into the LATE (local average treatment effect) parameter of Imbens and Angrist (1994), defined in this context as the effect of tuition fee change on the earnings of those induced to go to university, we find that the tuition policy produces a two-way flow. Some people who would have attended university in the bench-mark regime no longer do so. The rest of society is also affected by the policy — again, contrary to the implicit assumption built into LATE that only those who change status are affected by the policy. People who would have gone to university without the policy and continue to do so after the policy are financially worse off for two reasons: (1) the price of their skill is depressed; and (2) they must pay higher taxes to finance the policy. However, they now receive a tuition fee subsidy and, for this reason, on net, they are slightly better off both financially and in terms of utility. Those who would abstain from attending university in both steady states are essentially indifferent between the two steady states. They pay higher taxes, but their skill becomes more scarce and their wages rise. Those induced to attend university by the policy are better off in terms of utility but are not better off in terms of income. Note that neither category of non-changers is a natural bench-mark for a 'difference-in-differences' estimator. The movement in their wages before and after the policy is due to the policy and cannot be attributed to a bench-mark 'trend' that is independent of the policy.

Table 3 presents the impact of the $5,000 tuition policy on the log earnings of individuals with 10 years of work experience for different definitions of 'treatment effects'. The partial equilibrium version given in column 1 holds skill prices constant at initial steady-state values. The general equilibrium version given in column 2 allows prices to adjust when university enrolment varies. Consider four parameters initially defined in a partial equilibrium context. The *average treatment effect* is defined for a randomly selected person in the population in the bench-mark economy and asks how that person would gain in wages by moving from high school to university. The parameter *treatment on the treated* is defined as the average gain over their non-university alternative of those who attend university. The parameter *treatment on the untreated* is defined as the average gain over their university wage received by individuals who did not attend university. The *marginal treatment effect* is defined for individuals who are indifferent between going to university and not. It is a limit version of the LATE parameter under conventional assumptions made in discrete choice theory, as first noted by Heckman (1997). Taber (1997) makes use of this parameter in his analysis of schooling choices and Heckman and Vytlacil (1999) formally develop its properties. Column 2 presents the general equilibrium version of *treatment on the treated.* It compares the earnings of university graduates in the bench-mark economy with what they would earn if no one went to university.[1] The *treatment on the untreated* is defined analogously by comparing what high-school graduates in the bench-mark economy would earn if everyone in the population were forced to go to university. The *average treatment effect* compares the average earnings in a world in which everyone attends university with the earnings in a world in which nobody attends university. Such dramatic policy shifts produce large estimated effects. In contrast, the general equilibrium *marginal treatment effect* parameter considers the gain to attending university for people on the margin of indifference between attending university and attending high school. In this case, as long as the mass

[1]In the empirical general equilibrium model of Heckman, Lochner and Taber (1998), Inada conditions for university and high school are not imposed and the marginal product of each skill group when none of it is utilised is a bounded number. If Inada conditions were imposed, this counterfactual and the counterfactual *treatment on the untreated* would not be defined.

TABLE 3

Treatment Effect Parameters: Difference in Log Earnings, University Graduates versus High-School Graduates at 10 Years' Work Experience

Parameter	*Prices fixed*[a] *(1)*	*Prices vary*[b] *(2)*	*Fraction of sample*[c] *(3)*
Average treatment effect	0.281	1.801	100%
Treatment on the treated	0.294	3.364	44.7%
Treatment on the untreated	0.270	−1.225	55.3%
Marginal treatment effect	0.259	0.259	—
LATE,[d] *$5,000 subsidy*			
Partial equilibrium	0.255	—	23.6%
General equilibrium:			
high school → university (LATE)	0.253	0.227	2.48%
university → high school (LATER)	0.393	0.365	0.34%
net (TLATE)	—	0.244	2.82%
LATE,[d] *$500 subsidy*			
Partial equilibrium	0.254	—	2.37%
General equilibrium:			
high school → university (LATE)	0.250	0.247	0.24%
university → high school (LATER)	0.393	0.390	0.03%
net (TLATE)	—	0.264	0.27%

[a]'Prices fixed' denotes the difference in log earnings between university and high-school graduates conditional on various groups. Prices are held constant at their initial steady-state levels when wage differences are calculated.
[b]In column 2, we allow prices to adjust in response to the change in schooling proportions when calculating wage differences.
[c]For each row, column 3 presents the total fraction of the sample over which the parameter is defined.
[d]The LATE group denotes the effect on earnings for persons who would be induced to attend university by a tuition policy change. In the case of general equilibrium, LATE measures the effect on individuals induced to attend university when skill prices adjust in response to quantity movements among skill groups. The partial equilibrium LATE measures the effect of the policy on those induced to attend university when skill prices are held constant at the bench-mark level.

of people in the indifference set is negligible, partial and general equilibrium parameters are the same.

The final set of parameters we consider are versions of the LATE parameter. This parameter depends on the particular intervention being studied and its magnitude. The partial equilibrium version of LATE is defined on the outcomes of individuals induced to attend university, assuming that skill prices do not change. The general equilibrium version is defined for the individuals induced to attend university when prices adjust in response to the policy. The two LATE parameters are quite close to each other and are also close to the *marginal treatment effect*.[2] General equilibrium effects change the group over which the parameter is defined compared with the partial equilibrium case. For the $5,000 subsidy, there are substantial price effects and the partial equilibrium parameter differs markedly from the general equilibrium parameter.

We also present partial and general equilibrium estimates for two extensions of the LATE concept: LATER — the effect of the policy on those induced to drop out of university and go to high school, or Reverse LATE — and TLATE — the effect of the policy on all those induced to change whichever direction they flow. LATER is larger than LATE, indicating that those induced to drop out of university have larger gains from dropping out than those induced to enter university have from entering. TLATE is a weighted average of LATE and LATER with weights given by the relative proportion of people who switch in each direction.

VI. SUMMARY

This paper defines and estimates general equilibrium 'treatment effects'. The lessons from partial equilibrium analyses are substantially misleading guides in analysing the effects of tax and tuition policy on skill formation. Changes to proportional taxation are unlikely to have large effects on skill formation or output. A change to a flat consumption tax has the largest effect on output, consumption and real wages, but it also slightly raises wage inequality. These conclusions also hold for open economy simulations in which the interest rate is set in world markets (see Heckman, Lochner and Taber (1999)). They are robust to a variety of tax schedules and empirically grounded parameter estimates.

Regarding the impact of tuition policy, we find that general equilibrium impacts of tuition fees on university enrolment are an order of magnitude smaller than those reported in the literature on microeconometric 'treatment effects'. The assumptions used to justify the LATE parameter in a microeconomic setting do not carry over to a general equilibrium framework. Policy changes, in general, induce two-way flows and violate the monotonicity — or one-way-flow — assumption of LATE. We extend the LATE concept to allow for the two-way flows induced by the policies. We present a more comprehensive approach to programme evaluation by considering both the tax and benefit consequences of the analysis in a market setting.

[2]The latter is a consequence of the discrete choice framework we use to model schooling choices in our model. See Heckman (1997).

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