Commute Costs and Labor Supply: Evidence from a Satellite Campus*

Abstract

Whether, and how much, increased commute costs decrease labor supply is important for transport policy, city growth, and business strategies. Yet empirical estimates are limited and biased downward due to endogenous choices of residences, workplaces, commute modes, and wages. Using the transition of undergraduate teaching from a university's urban to suburban campus we test how labor supply responds to a longer commute. Exogeneity is ensured because few faculty change residences, nearly all use a free shuttle, and we control for wages.

Based on difference-in-difference estimates using individual changes in commute time, the 1.0 to 1.5-hour (40-kilometer) increase in round-trip commute time reduces annual undergraduate teaching hours by 53 (21%). Consistent with higher per-day commute costs, annual undergraduate teaching days decrease by 18 while daily undergraduate teaching hours increase by 0.16. Substitution to alternative work activities is minor: graduate teaching increases by a small amount and research output decreases significantly. These results imply work time is highly responsive to commute time for workers with flexibility. The university accommodated the reduced teaching time primarily by increasing class sizes implying that education quality declined. While larger classes may have increased preparation time outside class, we show that class size changes are only minimally correlated with the increased commute costs and do not confound our estimates.

Keywords: commuting; commute costs; labor supply; value of time; satellite campus
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1. Introduction

Because commute costs are variable with respect to work days but fixed within a work day, theoretically a longer commute can either increase or decrease total work time depending on the relative changes in days worked and daily hours (Cogan, 1981; Parry and Bento, 2001).[1] In what direction, and how much, commute costs affect work time is therefore an empirical question. Because controlling for endogeneity and selection bias in estimation are difficult, extant answers are limited and biased downward. Using a unique empirical setting, we estimate the causal effect without selection bias and find a large work time reduction for a group of workers with flexible work time.

A significant labor supply response to commute costs has important ramifications for government policy, city growth, and business strategies.[2] Cost-benefit analyses of transportation infrastructure investments and traffic congestion policies should consider not only the opportunity cost of commute time changes but also the accompanying change in labor supply and therefore output. The negative relationship between congestion and long-run employment growth (Hymel, 2009 and Duranton and Turner 2008), the presence of coordination and knowledge spillovers in cities (Moretti, 2004), and the longer commute times and distances caused by urban sprawl (Glaeser and Kahn, 2001) imply that commute time's influence on labor supply plays a role in city growth. For firms, understanding the causal effect of commute costs on labor supply helps them design policies to attract talent and influence their work time and productivity.

Quantifying commute costs' effect on labor supply has been difficult because they are endogenous and suitable instruments are scarce.[3] Workers consider commute costs when choosing residences, job locations, and commute modes and firms consider them when choosing wages and locations.[4] Workers with high commute-cost sensitivity are likely to choose residence-job combinations with short commutes while workers with low sensitivity are likely to tolerate those with longer commutes. Failing to correct for endogeneity will understate commute costs' effect on work time. Measuring commute costs is also difficult. Commute costs can include time, monetary costs, and disutility and even time and distance are usually measured imprecisely.[5]

Most extant evidence on this question is either indirect or subject to endogeneity. Gibbons and Machin (2006) state there is no direct empirical evidence of commute

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[1] Daily work hours could also change as workers adjust their start and end times to avoid congested periods of the day as in "bottleneck" theories examined by Vickrey (1969); Arnott, de Palma, and Lindsey (1990, 1993); and Arnott, Tilman, and Schöb (2005).

[2] Commute time may also influence labor supply through the labor participation rate. We are able to measure only the increase in work time of already-employed workers.

[3] Burchfield, *et al.* (2006) emphasize quantifying the consequences of urban sprawl but note the necessity of using good instruments.

[4] Many papers examine these equilibrium outcomes. Manning (2003) and Mulalic, Van Ommeren, and Pilegaard (2013) provide empirical evidence on the positive relationship between commute costs and wages. Gin and Sonstelie (1992) examine residential location changes due to commute cost changes. Zax (1991) and Zax and Kain (1996) empirically examine residence and job changes in response to commute cost changes. Van Ommeren and Rietveld (2005) provide a theoretical relationship between commute time and wages in a job-matching model. White (1988) provides a theoretical model of location choice with endogenous residence and work locations.

[5] Examples of monetary commute costs are gasoline, depreciation, and tolls. Disutility includes discomfort from noise, pollution, or effort.

time's causal effect on labor supply. The only subsequent papers we know of that deal with the endogeneity issue are Gutierrez-i-Puigarnau and van Ommeren (2010a), Gutierrez-i-Puigarnau and van Ommeren (2014), and Gershenson (2013). The first two use workplace relocations and exclude workers who change residences to maintain exogeneity. While this solves the in-sample endogeneity problem, it understates the out-of-sample effects because workers who change residences have high commute-cost sensitivity. The commute costs measures may also involve error because transport mode is unobserved in the first paper and commute time is self-reported in the second. The effects for the in-sample groups are small: fifteen fewer work minutes per week from an extra forty kilometers in daily round-trip commute distance in the first paper and an insignificant effect of commute time in the second. Gershenson (2013) uses random daily assignments of substitute teachers to schools to overcome the endogeneity problem and estimates commute time's effect on teachers' daily job acceptance probabilities rather than their work time.

Our causal estimates are based on the addition of a suburban satellite campus to a main urban campus at a typical, well-established Chinese university. For classes taught at the satellite campus, commute time increases exogenously since faculty has a strong financial incentive not to quit or move their residences to the satellite campus and virtually none do. Moreover, the increased time and distance are known and homogeneous across teachers[6] since virtually all faculty live at or near the main campus and ride a free university shuttle bus. Faculty chose their teaching time within an internal labor market subject to a linear wage[7] allowing us to measure the market response of work time.

Using teacher-level variation in commute time during the transition of undergraduate teaching to the satellite campus, we identify the causal effect of commute time on undergraduate teaching time. The satellite campus opens in academic year 2004[8] (a "year" will refer to an "academic year" unless otherwise noted) but undergraduate students transition one class level per year until all four levels are taught there in 2007. This incremental transition imposes different commute costs on different teachers in different years during the transition depending on their course schedule. Teaching a freshmen course[9] imposes a longer commute sooner because freshmen transition first. Teaching a sophomore course imposes a longer commute next soonest, followed by teaching a junior course, and finally teaching a senior course. This allows a difference-in-differences (DD) analysis comparing work time effects for teachers with differential changes in commute time. This is immune to confounding factors not correlated with individual-level commute time. In particular, university-wide changes such as wages, student body size, faculty size, class size, and teaching load are differenced out. We provide evidence that possible individual-level confounders do not materially affect our estimates – in particular changes in class size.

[6] For brevity, we will use the terms "teacher" and "teachers" interchangeably with "faculty member" and "faculty" even though our sample includes faculty who both teach and research.
[7] We discuss later the possibility of administrators intervening in the market and applying non-wage pressures.
[8] As in U.S. universities, academic year t spans fall semester of calendar year t to spring semester of calendar year $t + 1$.
[9] When we use the term "course," we allow for the possibility of multiple sections. We therefore use the term "class" to refer to a course with a single section or one section of a course with multiple sections.

The 1.0 to 1.5 hour increase in commute time per teaching day reduces annual undergraduate teaching time by 53 “class hours” (a “class hour” is the amount of time a faculty member spends in the classroom to receive one “hour” of pay) per teacher after the full transition or 21% of the pre-transition average of 249 “class hours.” The elasticity of work time with respect to commute time is -0.12 and teachers value commute time at 44 to 60% of their hourly wage. Since commute costs vary with days worked but are fixed with respect to daily hours conditional on working that day, the transition should decrease work days but increase daily hours. Consistent with this, we find that the full transition to the satellite campus reduces a teacher’s annual undergraduate teaching days by 17.7 and increases a teacher’s daily undergraduate “class hours” by 0.16. This makes confounding factors even more unlikely. They must decrease days worked but increase daily hours and operate at the individual faculty level – affecting those with longer commute times by more than those with shorter.

Although the opportunity to do so is limited, teachers with high commute-cost sensitivity may try harder to shift away from teaching class levels that transition earlier which would bias our estimates toward zero.[10] As a check on the extent of endogeneity we estimate comparing before (2000 to 2003) versus after (2007 to 2009) the transition of all four undergraduate class levels to the satellite campus. These estimates are immune to endogeneity because after the full transition avoiding commuting for undergraduate teaching is impossible. The before-after estimate is an annual decrease of 56 undergraduate “class hours” per teacher – only slightly larger than the DD estimates consistent with a small endogeneity bias. Unlike the DD estimates, these may be subject to confounding factors at the university level although we include variously teacher fixed effects, year fixed effects, and teacher-specific time trends as controls.

Faculty may substitute to other work activities to offset the reduced undergraduate teaching time. Possibilities include graduate teaching, research, and consulting. Since the location of these is unaffected, they become relatively more attractive once undergraduate teaching transitions. However, time spent on these activities might decrease if increased time and fatigue from commuting crowds them out. The effect on graduate teaching is small and only marginally significant. The full transition increased graduate teaching time by only 6.1 “class hours” annually per teacher for those engaged in graduate teaching and far fewer faculty teach graduate students. Research output falls with the number of published academic research papers decreasing by 0.17 annually per teacher (16.8%). We are unable to observe consulting time but the drop in undergraduate teaching time for assistant professors, who rarely consult, are similar to the effect across all faculty. Unless research productivity fell dramatically, time diverted to other work activities is minimal and the total decrease in work time approximately equals the decrease in undergraduate teaching time.

Since we do not observe preparation time outside the classroom we cannot quantify the effect on work time inclusive of it.[11] If preparation time per “class hour” remained

[10] This endogenous avoidance behavior is separate from consolidating classes in fewer teaching days to avoid longer commutes – the causal effect we estimate. It is also separate from the possible substitution toward other activities discussed below.

[11] This problem is faced by any study of work time since unofficial work is unobserved as is sharing of household chores and paid work within the household (Knowles, 2013).

unchanged after the transition then our estimates understate the decrease in total work time by the ratio of preparation time to in-class plus preparation time. If preparation time changed because of the transition then we need to worry whether this confounds our estimates. In particular, since the university accommodated the decreased in-class teaching time primarily by increasing class sizes, preparation time outside class may have increased leading faculty to further reduce their workloads. However, if increased preparation time is uncorrelated with individual changes in commute time then the DD estimates are unbiased. We provide evidence that class size increases are correlated with increased commute time at the individual level but the magnitude is small. Thus, most of the effect of class size increases will be differenced out in our estimates. Consistent with this, controlling for class size at the individual teacher level does not materially affect the estimated effect of commute time on “class hours.”

As teachers have more flexibility on the intensive margin of labor supply their response will be greater than those whose work time is more constrained. Our estimates therefore provide an upper bound for constrained workers and an indication of how work time responds for workers with significant flexibility. A nontrivial fraction of workers have significant discretion over their work time and this fraction is expected to increase.[12] The proportion of “knowledge workers,” who generally have flexible schedules, is projected to increase over time (Moretti, 2012) and smartphone applications like Uber, Handy, and TaskRabbit are allowing increasing numbers of people to work flexibly.[13]

The next two sections provide institutional and theoretical background for our estimates. We then provide the econometric model, data, and results before concluding.

2. Institutional Details

We examine commute costs created from transitioning the location of undergraduate teaching at a well-established Chinese university.[14] The university is a research institution serving both undergraduate and graduate students and is a highly-ranked specialized (in particular academic disciplines) rather than general university. Capacity-constrained and faced with acquiring very expensive land adjacent to the original campus in the city center, the university decided to add a satellite campus 20 kilometers away in a suburban area.

Planning began in calendar year 2000 with a search for land and the university signed a contract with the city government to buy a parcel the next calendar year. Bidding for the campus design was held in calendar year 2002 and later that year a national newspaper announced that incoming freshman would live and be taught at the satellite campus beginning in 2003, later postponed to 2004. The timing of this announcement is critical because it means that prior to late 2002 faculty was aware that a campus

[12] “Millennials at Work: Reshaping the Workplace,” (PwC, 2011) estimates that 32% of millennials expect to have mainly flexible working hours in the future.
[13] “There’s an App for That,” *The Economist*, January 3, 2015. According to a survey of 5,000 working Americans 34% engage in some form of freelancing (“Freelancing in America: A National Survey of the New Workforce,” Elance-oDesk, 2014).
[14] For confidentiality reasons we cannot identify the university nor can we provide references for the background information on the campus opening all of which were obtained from local newspapers.

was being built but unaware of the transition timing. This is after academic year 2002 had begun and teaching schedules had been finalized for that year. Therefore, any faculty efforts to change their teaching schedule away from teaching freshman classes (to delay commuting) began in academic year 2003 at the earliest.

The school held a groundbreaking ceremony in early calendar year 2003 and in academic year 2004 the entering freshmen lived and took courses at the satellite campus while higher class levels remained at the main campus. In 2005, the entering class again lived and took courses at the satellite campus so that freshman and sophomores took courses at the satellite campus while juniors and seniors remained at the main campus. In 2006 only seniors remained at the main campus while the other class levels lived and took courses at the satellite campus. From 2007 onward all four class levels lived and took courses at the satellite campus. Our data spans the years 2000 to 2009. This provides four years before the transition and three years in which all four undergraduate class levels took courses at the satellite campus.

Graduate courses remained at the main campus during the undergraduate transition. Entering Master's students began taking courses at the satellite campus in 2008. Since they generally study for two years, one-half of them were at the satellite campus in 2008 and all of them were at the satellite campus in 2009.[15] Entering Ph.D. students began taking courses at the satellite campus in 2009. Since most Ph.D. students study for three years, approximately one-third took courses at the satellite campus in 2009. After the end of our sample period, Ph.D. students finished transitioning to the satellite campus and executive MBA, professional education, continuing education, some business classes, some research institutes, and some offices remained at the main campus.

Almost all teachers resided at or near the main campus during the sample period because the university continued to provide subsidized housing at the main campus and did not complete construction of subsidized housing at the satellite campus until after 2010.[16] The university provided a convenient shuttle bus between the two campuses by which virtually all faculty commuted. The shuttle was free so we estimate the effect of increased commute time but not monetary costs. The shuttle trip takes about thirty minutes one way plus up to fifteen minutes of walking and waiting on each end. Since the time required depends on random variation in weather, traffic, and wait times, we assume that commute time increased 1.0 to 1.5 hours round-trip per commute day (a "teaching day" refers to a day on which a faculty member teaches at least one class regardless of location while a "commute day" refers to a "teaching day" at the satellite campus).

Our primary data consists of the university's complete undergraduate class schedule from 2000 to 2009. For each class we know its course title, academic semester, teacher, class level (freshman, sophomore, junior, senior, other), number of students (class size), day and time of meeting, weekly "class hours," and number of weeks. We can identify class level because in China most undergraduate courses are taught to a

[15] Most Master's programs in China take three years but some universities, including this one, have two-year programs.
[16] Limited faculty offices and overnight dorms were available at the satellite campus and might limit the teaching time decline resulting from the longer commute.

single class level. This is important since it allows us to determine which classes were taught at which campus during the transition.[17]

Our primary measure of labor supply is a "class hour" (fifty minutes at the main campus and forty-five minutes at the satellite campus). We do not observe time spent outside of class preparing, grading, and responding to students. If outside time remains the same per "class hour" after versus before the transition, our estimates can be scaled up by the appropriate multiplier to obtain total hours from "class hours" and our estimates are not biased. If preparation time increased because of the transition (e.g., due to the accompanying increase in class size) our estimates would be biased. We present evidence when we discuss our results that any changes in per-"class hour" preparation time are orthogonal to changes in commute time so that our DD estimates are unbiased.

Teachers allocate their time among five major activities: undergraduate teaching, graduate teaching, research, consulting, and leisure. A teacher's total annual compensation can be represented as $F + B(T^R) + w^U T^U + w^G T^G$. F is a fixed payment based on seniority, position, and administrative duties and is primarily based on a nationwide standard. B is an annual bonus paid for research publications where T^R is time spent on research and we assume that there are diminishing or constant returns to research ($B(0) = 0$, $B' > 0$ and $B'' \leq 0$). Research also provides non-pecuniary benefits such as prestige, personal satisfaction, and future career advancement and we can think of B as including these effects as well.[18] The last two components are the linear payments for teaching where w^U and w^G are "hourly" wages for undergraduate and graduate teaching and T^U and T^G are annual "class hours" taught for each.[19] The "hourly" undergraduate wage increased over time: RMB 20 in 2001 and 2002, RMB 40 in 2003 and 2004, RMB 60 from 2005 to 2007, and RMB 90 from 2008 onward.[20] Domestic faculty were compensated for a graduate "class hour" at 1.5 times the rate for undergraduate "class hours" and those with a foreign Ph.D. (from a non-mainland China university) were compensated at the same rate for both. F, B, w^U, and w^G are otherwise common to all faculty and do not change within academic years.

The minimum annual teaching load was 240 "class hours" from 2001 to 2004 and 225 hours from 2005 onward.[21] Teachers are paid for "class hours" both used to satisfy their teaching load and those above. Teachers may fulfill this requirement through

[17] Three categories of courses are offered to all class levels – "sports," "university," and "double degree" courses – which we call "other." "Sports" courses teach athletics and "university" courses relate to culture or personal development. Courses are usually taught only to students within a major (corresponding to a university department) and only to a single class level. The exceptions to this, "double-degree" courses, are offered to students outside of the major and can be taken by any class level.

[18] Faculty with a foreign Ph.D. and domestic faculty hired since 2006 have three-year contracts. All other domestic faculty has permanent contracts. Regardless of contract length, research output affects promotion from an assistant to an associate or from an associate to full professor.

[19] We discuss one exception to this linearity below in our robustness check for "paid hours."

[20] We do not believe that faculty anticipates wage changes because they are determined by human resources or a university-level committee and only then announced to faculty members. Therefore, they will not change their teaching schedules dynamically in anticipation of wage changes.

[21] This is for department-specific courses. For "university-wide" and "sports" courses the minimum was 320 "class hours" per year from 2001 to 2004 and 300 from 2005 onward. These courses are taught primarily by faculty in the English, sports, and math departments. For the few teachers with a foreign Ph.D. the minimum was 160 "class hours" per year. The university did not allow faculty to carry-forward or carry-back teaching credits and examined faculty workload year-by-year. The financial penalties for not meeting the teaching load were severe.

other activities (and get paid for them) that we do not observe. These include supervising graduate theses, administrative tasks, and supervising student internships and study trips.[22] Therefore, many faculty have fewer “class hours” than the minimum.

Unlike at many American universities in which department heads or deans have more control, faculty at most Chinese universities including the one we study have great discretion in choosing their teaching time. Subject to the wage and minimum teaching load (there is no maximum) a teacher chooses teaching hours to maximize their utility. The process is the following. Each faculty member submits their chosen courses to the department staff which figures out course scheduling. The schedule is submitted to a university-wide administrative office that assigns classrooms. At the university we study faculty could also choose their teaching time in fine increments for three reasons. First, course credits range from one to six. A course credit corresponds to one “class hour” per week over a 16-week semester. Thus, courses allow annual teaching time to be chosen in increments as small as 16 “class hours.” Second, co-teaching arrangements further reduce this increment. Co-teaching with one person allows annual teaching time to be chosen in increments of eight “class hours” and co-teaching with more than one faculty member is allowed and common. Third, seminar-style classes, which meet once, allow faculty members to receive teaching credit in increments as small as two “class hours.”

Figure 1 illustrates this flexibility. It shows the distribution of annual undergraduate “class hours” across all faculty members from 2001 to 2009. Although the distribution exhibits spikes at some multiples of course credits, it exhibits significant dispersion. Given faculty’s flexibility to adjust their “class hours,” how could the university accommodate a decrease in teacher “class hours” while still providing sufficient student “class hours”[23] for graduation and distribution requirements? The university could adjust along two dimensions: class sizes and faculty size. We provide rough numbers on the adjustment after we discuss our results.

Faculty members also had significant flexibility in allocating their “class hours” across days of the week. Classes of three credits or less met once per week and a faculty member could choose the day of the week. Longer classes met twice per week (e.g., a four-credit course meets twice per week for two “class hours” each day) and the faculty member could choose any two non-contiguous days. There was an overall constraint of not scheduling too many courses for a particular class level on the same day which might require “horse-trading” of days among colleagues.[24]

Faculty size, student enrollment, graduation requirements, and class sizes could affect university-level teaching demand. However, contractually the university could only require teachers to fulfill their minimum teaching load. Above this, the university could influence demand in the internal labor market only through the wage it offered. Department heads may attempt to pressure faculty to teach more or less. Pressure

[22] The activities available for meeting the minimum teaching load vary by rank. For example, only associate and full professors can supervise Masters’ theses and only full professors can supervise Ph.D. theses. We check the robustness of our results to this by including faculty rank controls in some specifications.
[23] One teacher “class hour” yields x student “class hours” where x is the class size being taught. Throughout the paper a “class hour” refers to a teacher “class hour” unless otherwise qualified.
[24] To the extent that this constraint was binding during the transition years it was due to avoiding scheduling conflicts for students – the satellite campus was well below capacity without all class levels present.

applied to all teachers will be differenced out in our DD estimates. Individualized pressure would bias our results away from zero only if department heads systematically exerted more pressure on faculty facing longer commute costs to teach less. The opposite seems more likely. If a faculty member facing a commute to teach freshman at the satellite campus were convinced to teach less the department head would have to then convince another teacher unfamiliar with the course to commute and teach it.

3. Theoretical Background

We model the effect of increased commute time on daily "class hours," annual teaching days, and annual "class hours." For manageability, we first consider a model with no graduate teaching or research ($T^G = T^R = 0$) so that all work time is subject to commute costs and all teaching days are commute days. We reintroduce these in an alternative model in Appendix B. Because additional commute time increases fixed costs per teaching day, faculty will concentrate more "class hours" per day in fewer annual teaching days. Total teaching time could increase or decrease. We show this using a modified version of the model in Gutierrez-i-Puigarnau and van Ommeren (2009). They generalize a labor supply model with commute costs to allow for the choice of days worked and daily hours. We adapt their model to our setting in two main ways. Their model allows for a concave wage function due to declining marginal productivity. We instead use a linear wage function and assume that a convex effort cost diminishes the value of leisure. We also exclude monetary commute costs consistent with the university's free shuttle service. The two models' implications are qualitatively similar.

A teacher's annual utility is $v = V(C, L)$ where C is annual consumption, L is annual leisure time, and V is differentiable with $V_L > 0, V_C > 0, V_{LL} < 0, V_{CC} < 0$, and $V_{CL} > 0$. Without graduate teaching and research, annual compensation is $F + w^U DH$ where annual undergraduate "class hours" (T^U) is decomposed into annual days (D) and daily "class hours" (H). A teacher's annual budget constraint is $C = Y + F + w^U DH$ where Y is annual non-labor income. Annual time is divided between undergraduate teaching and leisure and each teaching day requires round-trip commute time of t.[25] Daily "class hours" require effort that decreases utility from daily leisure by $e(H)$ with $e'(H) > 0$ and $e''(H) > 0$ denominated in leisure hours. The disutility can be interpreted as diminishing the quality of each leisure hour or additional time spent resting to recover from the fatigue of commuting. Although we have stated annual teaching days, daily "class hours," and annual "class hours" in terms of in-class time, it is simple to allow for exogenous fixed preparation time outside the classroom. If total work hours per "class hour" is $H' = \rho H$ with $\rho > 1$, we can redefine the effective hourly wage as $w^{U\prime} = w^U/\rho$ and all the results go through.

A teacher's annual time constraint is $\bar{T} = L + D\big(H + t + e(H)\big)$ where $\bar{T}$ is total annual hours. Substituting the budget and time constraints:[26]

[25] As discussed earlier, teachers may have other work obligations besides teaching such as consulting. Time spent on these is subsumed into leisure and income from these is subsumed in Y. Our model assumes an equal number of "class hours" across teaching days. In our data they are unevenly distributed but this does not qualitatively change the model's implications.

[26] The problem should also include constraints on the maximum number of daily "class hours" and for the minimum teaching load. For simplicity, we assume an interior solution.

(1) $v = V\left(Y + F + w^U DH, \bar{T} - D\big(H + t + e(H)\big)\right)$.

The two first-order conditions are

(2) $F_H \equiv \partial v/\partial H = V_C w^U D - V_L D\big(1 + e'(H)\big) = 0$, and
(3) $F_D \equiv \partial v/\partial D = V_C w^U H - V_L\big(H + t + e(H)\big) = 0$.

Equation (2) says that the marginal utility of consumption from an extra daily "class hour" equals the foregone marginal utility of daily leisure including the effect of fatigue. Equation (3) says the same from working an extra teaching day during the year. Combining these two, the optimally chosen daily "class hours" fulfills

(4) $e'(H) = \frac{t+e(H)}{H}$.

The teacher equates the marginal disutility of effort to the average daily disutility of working (including commute time and effort). The teacher smoothes daily "class hours" across days to avoid escalating the costs from working very long days (e.g., it is better to have two ten-hour days than one twenty-hour day).[27] If we totally differentiate Equation (4) letting daily "class hours" adjust to a change in commute time, it follows that an increase in daily commute time increases daily "class hours"

(5) $\frac{dH}{dt} = \frac{1}{e"(H)H} > 0$.

Given a longer daily commute, teachers work more "class hours" once at the satellite campus so as to avoid additional trips on other days. In Appendix A we show that increased commute time decreases annual teaching days. Teachers concentrate their teaching in fewer days to avoid the extra commute time incurred each teaching day. Thus, increased commute time increases daily "class hours" but decreases annual teaching days. In Appendix A we show that increased commute time could increase or decrease annual "class hours" (DH). Which happens depends in particular on the curvature of the effort costs. If effort costs do not increase too rapidly with daily "class hours" then increased commute time may increase annual "class hours."

In Appendix B we modify the model to consider two work activities – one affected by commute time (undergraduate teaching) and the other not. The other activity could either be paid according to a wage linear in hours worked (as with graduate teaching) or increase a teacher's annual bonus according to a weakly concave function of hours worked (as with research). To simplify the analysis we collapse the separate choices of annual teaching days and daily "class hours" into a single choice of annual "class hours" for each activity. The model shows that time spent on the other activity could increase or decrease with commute time when undergraduate teaching time decreases. Faculty may substitute toward these activities since they do not require commuting; however, increased commute time may crowd them out.

[27] Consistent with this, Connolly (2008) finds that male workers increase their work time on rainy days and decrease it the following day to equalize the marginal utility of leisure across days.

4. Econometric Model

We model teacher i's work time in academic year $2000 \leq t \leq 2009$ as:

(6) $Y_{it} = \alpha_i + g_i(t) + \beta\left[\cup_{c\in Q}(Tr_t^c CD_{it-1}^c)\right] + X_{it} + \tilde{\varepsilon}_{it},$

where Y_{it} is one of three measures of work time (annual "class hours," annual teaching days, and daily "class hours"), α_i is a teacher fixed effect which absorbs time-constant unobserved work-time preferences, and $g_i(t)$ is a potentially teacher-specific function of academic years that captures time-specific unobserved factors affecting work time. The term in brackets captures a teacher's commute days in year t where $Q = \{Fr, So, Ju, Se\}$ is the set of four class levels (freshman, sophomore, junior, and senior), CD_{it}^c is the number of days teacher i would have to commute to the satellite campus based on their academic-year t schedule and assuming that class level c students had transitioned to the satellite campus, and Tr_t^c is a dummy variable set equal to one beginning in the academic year in which level c has transitioned to the satellite campus and zero before. We control for teacher/year-specific characteristics X_{it} such as rank. Time-varying, university-wide characteristics are subsumed in $g_i(t)$. These include wages, student enrollment, faculty size, class size, curriculum, graduation course requirements, and national education policies. β captures the effect of increased commute days on work time.

The model assumes that year t commute days is proportional to the commute days a teacher would incur based on their year $t-1$ teaching schedule. For example, in 2004 freshmen transitioned to the satellite campus. The expected number of commute days in 2004 is equal to the number of unique dates that a teacher taught a freshman-level class in 2003. Consider a teacher who taught sixteen weeks in 2003 and taught two freshman classes on Tuesday, one freshman class on a Thursday, and only non-freshman classes all other weekdays. Their expected number of commute days in 2004 would be 32 (two unique commute days per week for sixteen weeks). We use the union of commute days across all class levels that have transitioned to the satellite campus because teaching two different class levels that have transitioned to the satellite campus on the same day requires only one commute day.

We believe lagged teaching schedule is the best basis for expected commute time in the current year. A teacher's current schedule is invalid because it is simultaneously determined (if commute time decreases teaching time it will also decrease the contemporaneous number of commute days). Using the lagged teaching schedule is problematic in that teachers' schedules may change over time for random and non-random reasons. Random reasons such as changes in students' or teachers' interests will introduce noise and make estimates less precise. Of more serious concern is that teachers may alter their schedule in non-random ways that introduce bias; in particular they may attempt to shift away from teaching class levels that impose a longer commute. For example, between 2003 and 2004 teachers may try to change their schedule to avoid teaching freshman-level classes. This avoidance behavior is separate from the causal effect of teachers attempting to consolidate their teaching into fewer teaching days. The former biases estimates of the casual effect while the latter is the causal effect we want to estimate.[28]

This avoidance behavior is costly as it requires incurring fixed costs to develop a new course. Table 1 provides suggestive evidence that avoidance behavior is not significant. The upper panel shows the year-to-year change in the fraction of annual "class hours" by teacher by class level averaged across all faculty who taught in contiguous years.[29] We focus on freshman and sophomore classes since these are where avoidance behavior is most likely. The lower panel repeats the same calculations but excludes teacher-year observations in which the fraction was zero in both the current and previous years to avoid a downward bias from faculty not actively teaching. If avoidance behavior were significant we should see a decline in freshman and sophomore "class hours" beginning in 2003 when the transition sequence became known and continuing into the transition period. Neither the freshman nor sophomore data exhibits evidence of avoidance behavior. The only significant changes occur in 2007 or later, after the transition is completed.

Transition (DD) Model: We take advantage of individual commute-cost variation by using the fact that class levels transition one at a time each year to the satellite campus. Work time should be disproportionately affected for those who teach class levels that have transitioned relative to those who teach levels that have not. Focusing on the transition years (2004 to 2007) and taking first differences of Equation (6):

(7) $\Delta Y_{it} = f_i(t) + \beta\left(\bigcup_{c\in Q} Tr_t^c CD_{it-1}^c - \bigcup_{c\in Q} Tr_{t-1}^c CD_{it-2}^c\right) + \Delta\varepsilon_{it};\ t = 04, \ldots, 07,$

where $f_i(t) = g_i(t) - g_i(t-1)$ and $\Delta\varepsilon_{it} = \varepsilon_{it} - \varepsilon_{it-1}$. We drop X_{it} because gender and foreign Ph.D. status do not change over time and few teachers change ranks during the transition. We show in Appendix C that Equation (7) is consistent with a model allowing for heterogeneous commute costs across teachers as long as these costs are independent of the individual's commute days and we allow for an error structure that is heteroskedastic and clusters standard errors by teacher.

Identification of DD Model: Our DD estimates use teachers with a non-zero change in expected commute days as the treatment group and compare how their work time is affected relative to the control group of those with no change in expected commute days. The parenthetical term in Equation (7) – the change in expected commute days – captures the intensity of the treatment effect. Identification of the treatment effect requires that conditional on $f_i(t)$ this term is uncorrelated with $\Delta\varepsilon_{it}$, the change in any omitted factors. Bias will be introduced if confounding factors not controlled for by $f_i(t)$ are correlated with teacher-specific changes in expected commute days.

Since we include academic year fixed effects in $f_i(t)$ this rules out university-level changes in wages, student enrollment, faculty size, class size, curriculum, graduation course requirements, and national education policies since these are constant within

[28] A similar issue arises in the environmental literature. In estimating the causal effect of pollution on health outcomes it is important to control for the fact that people will avoid the impact of pollution by, for example, spending less time outside or wearing protective masks (Zivin and Neidell, 2013).

[29] This is not a tautology: annual "class hours" per teacher ("class hours" summed across all courses taught by a teacher) can change on average across all teachers even as total student "class hours" across all students stays the same as the university changes class sizes or number of faculty.

an academic year. Online courses were not used by the university and teaching support and research fund guidelines did not change over time. We also include teacher fixed effects which control for any teacher-specific changes affecting work time that are invariant across years. Time-varying, teacher-specific changes could bias the estimates but only if correlated with individual expected commute days. For example, individual-level changes in returns to outside activities such as consulting would bias the estimates only if they were somehow correlated with individual expected commute days.

Bias is not introduced by random changes in the distributions of a teacher's classes across academic years (i.e., CD_{it}^{c} may randomly differ from CD_{it-1}^{c}) but it is by purposeful changes by a teacher to avoid commute costs. To the extent that this occurs it will tend to understate commute costs' effects. If teachers on average substitute away from teaching classes held at the satellite campus then our lagged measure of commute days will be overstated. The regression will attribute too small an effect (in absolute value) of commute days on work time.[30] Besides the evidence in Table 1, another check for endogenous avoidance behavior is before-after estimates that compare pre- and post-transition years. Since all four class levels are taught at the satellite campus post-transition, avoidance behavior is impossible. We next describe this model.

Before-After Model: The before-after model uses the "before" and "after" years:

(8) $Y_{it} = \alpha_i + g_i(t) + \beta D_t + X_{it} + \varepsilon_{it};\ t \in \{00, \ldots, 03; 07, \ldots, 09\}$,

where D_t is a dummy variable equal to one after all class levels have transitioned ($t \in \{07, \ldots, 09\}$) and zero before ($t \in \{00, \ldots, 03\}$). The coefficient of D_t captures the average effect across all teachers on the outcome variable Y_{it} of transitioning all class levels to the satellite campus. The change captured by β depends on the time controls included. We estimate two specifications. If $g_i(t)$ includes academic-year fixed effects omitting years 2003 and 2007 then β captures the policy's short-run effect from 2003 to 2007. We alternatively include a teacher-specific quadratic time trend to control for time-varying, teacher-specific unobservables. In this case β captures the average effect in years 2007 to 2009 versus 2000 to 2003.

We show in Appendix C that Equation (8) is consistent with a model allowing for heterogeneous commute costs across teachers as long as these costs are independent of the individual's commute days and we allow for heteroskedasticity and serial correlation within but not across teachers. We therefore cluster standard errors in cells defined by a teacher before versus after the transition and allow for heteroskedasticity.

Identification of Before-After Model: Identification of the before-after effect requires that conditional on $\alpha_i, g_i(t)$, and X_{it}, D_t is uncorrelated with ε_{it}. That is, the controls are sufficiently flexible to capture any factors besides the commute costs that changed between 2003 and 2007. The fixed effects will capture any teacher-specific time-constant unobservables affecting work time. We use two main specifications for $g_i(t)$.

[30] We estimated a regression using commute days in academic years prior to the transition announcement as an instrument for lagged commute days in Equation (7). The results were statistically insignificant likely due to noise introduced by such a long time lag between the instrument and instrumented variable and a much smaller sample.

Academic-year fixed effects absorb university-level changes over time including wages, student enrollment, faculty size, class size, curriculum, graduation course requirements, and national education policies since these do not change within an academic year. This would also capture aggregate changes in the quality of outside options because teachers commit to a teaching schedule prior to the academic year and therefore must rely on the expected return to outside activities in the coming academic year in choosing their teaching time. Alternatively, teacher-specific time trends capture any secular trends affecting work time at the teacher level such as enhanced teaching skills from experience.

Despite these flexible controls, identification is more problematic than for the DD estimates. Confounding factors that do not change year-by-year but change only with the transition would be problematic; in particular, other repercussions of the transition that affect work time. The advantage of the before-after estimates is that they are immune to avoidance behavior. Therefore, we treat them as a check of whether our DD estimates are biased due to endogeneity.

5. Data

Our primary sample is the university's complete undergraduate course schedule provided by the university's Undergraduate Education Administrative office. We supplement this data with rank, gender, and Ph.D. source for each teacher from the university's website. A teacher is included in this sample as long as they taught at least one undergraduate course. If a teacher taught only graduate level courses or no classes at all they are not included.[31]

For each class, we use weekly "class hours" and number of weeks taught to compute total "class hours." For co-taught classes, we divide total "class hours" by the number of co-teachers to obtain total "class hours" for each teacher. We then aggregate across all classes for a teacher in a year to obtain annual "class hours" for each teacher-year observation. To determine the number of teaching days for each teacher we use the days of week for each class they teach to identify all the dates on which their classes are taught during the semester.[32] We then identify any overlap in these dates to obtain unique teaching dates for each semester. Aggregating across the two semesters, we obtain annual teaching days for each teacher-year observation. Finally, we compute daily "class hours" (conditional on teaching that day) for each teacher-year observation by dividing annual "class hours" by annual teaching days.

A second sample consists of graduate course information. Since we were unable to obtain complete graduate course data from the university's administration, we downloaded it from its graduate school website. As a result, we do not observe day

[31] We drop class-year observations taught by faculty appearing in only one year that would be dropped with taking first differences and those missing a teacher name. We also drop those taught by teachers under short-term contracts who are not permanent staff including visiting, retired, rehired (after retirement), and adjunct faculty. The number of observations for faculty rank information is slightly lower because we were unable to collect this information for some faculty.

[32] For co-taught courses we assign each teaching day to all teachers of the course. Although we would ideally allocate them proportional to the number of co-teachers this is impossible because these courses often meet multiple times per week and we do not observe which teacher teaches on which day. This makes it impossible to determine the overlap with each co-teacher's other courses. Since we are unable to allocate them we make the conservative assumption to overstate teaching days and therefore commute days.

and time of meeting or class size but we do observe course title, academic semester, teacher, weekly "class hours" and number of weeks. A teacher is included in this sample if they taught at least one graduate course. Teachers who taught only undergraduate courses or no classes at all are not in this sample.

A third sample consists of data on faculty research output from the university's Research Support Office website. We observe author's name, journal name, and publication date. Because it is important in both determining faculty salaries and promotions and establishing the university's reputation, we believe the data is accurate and comprehensive. During our sample period, China's Ministry of Education attributes research output only to the first author's affiliation. The university applied this same criterion in evaluating faculty so we count a paper only toward the first author. A teacher is included in this sample if they produced at least one paper during the sample period because faculty members producing no papers are likely not engaged in research. We designate papers as appearing in either "top" or "non-top" journals[33] and compute annual publications per teacher.

Table 2 contains descriptive statistics for the three samples in the four transition years. Panel A shows data for the 715 faculty teaching undergraduates and present in at least two contiguous years from 2003 to 2007. An observation is a teacher-year. On average, expected commute days increase by 16.7 each year of the transition although there is great variation. Annual undergraduate "class hours" and annual undergraduate teaching days decrease on average while daily undergraduate "class hours" increase but the variation in each is great.[34] Panel B summarizes the transition data for graduate teaching for the 275 faculty who taught undergraduate students in at least two contiguous years (necessary to compute the change in expected commute days) and taught graduate students in at least one year from 2003 to 2007. Annual graduate "class hours" increase on average but the variation is great. Panel C summarizes the research output data during the transition years. This includes the 771 teachers who taught either undergraduate or graduate students in at least two contiguous years and produced at least one research paper from 2003 to 2007. The changes in publications per capita are close to zero but the variation is great.

Table 3 summarizes how various undergraduate teaching variables evolve over time. The aggregate teacher "class hours" data in Column 7 hint at the effect that our formal tests reveal. Prior to the transition, "class hours" increase each year. They drop significantly in 2004 when the transition begins and remain low. Comparing Columns 1 and 2 shows that class-level-specific courses comprise a large and stable fraction of all classes over the sample period until 2009.[35] For our DD estimation we exclude "other" courses in our calculation of expected commute days because we cannot infer

[33] The Research Support Office ranks Chinese journals as "A1," "A2," "B1," "B2", or "C" and English journals as "A," "B," or "C." "A1" and "A2" Chinese journals are the top general interest and field journals in China. English "A" journals are top general interest journals and "B" are top field journals. Since publishing papers in English is difficult, we designate Chinese "A1" and "A2" and English "A" and "B" journals as "top." All other journals we designate as "non-top."

[34] Day and time is available for classes meeting on weekends only beginning with the second semester of 2005. Before this, we have no way of determining whether a missing value is due to the class being taught on a weekend or some other reason. To be conservative, we include weekend days taught as a teaching day after second semester 2005 but drop missing values both prior to and after this. This will understate teaching days prior to 2006 and bias us against finding a decrease in annual teaching days due to the transition.

[35] The drop in 2009 occurs because the university re-classified some courses that were department-specific and offered separately to the four class levels as university-wide courses taught to the four class levels collectively.

their location but include them in calculating work time. This will understate expected commute days and bias against finding an effect.[36] Table 3 also hints at how the university responded to the decreased teaching time: by increasing the average number of students per class.

6. Results

Annual Undergraduate "Class Hours": The top panel of Table 4 shows the results of DD estimates using Equation (7) with annual undergraduate "class hours" as the dependent variable. This relates individual-level changes in teaching time to individual-level changes in commute time during the transition years. Column 1 includes teacher fixed effects but no time controls $(f_i(t) = \alpha_i)$. This implies a teacher-specific linear time trend in the un-differenced equation. An increase of one additional expected commute day in a transition year decreases annual "class hours" by 0.60. In Column 2 we keep the teacher fixed effect and add academic-year fixed effects to capture aggregate time-specific unobserved factors ($f_i(t) = \alpha_i + \sum_t \rho_t \mathrm{I}_t$ where I_t is a dummy variable set to one in year t and zero otherwise and ρ_t are coefficients to be estimated). This implies academic-year fixed effects and a teacher-specific linear time trend in the un-differenced equation. This is our preferred specification and increases the estimate to -0.79. The remaining two columns show that this result is robust up to a second-order time trend.[37]

Since expected commute days increase by an average of 16.7 days per transition year, our preferred specification implies a decrease of 13.17 "class hours" annually per transition year. Multiplying by the number of transition years (four) implies annual "class hours" are reduced by 52.7 from the full transition – 21.2% of the average pre-transition of 249.0 annual "class hours." This implies an elasticity of -0.12 for work time with respect to commute time or distance.[38] Gutierrez-i-Puigarnau and van Ommeren (2010a) estimate an elasticity of -0.009 for work time with respect to commute distance, consistent with their excluding workers with high commute-cost sensitivity, the workers in our sample having more flexibility over work time, or both.

Robustness Checks: Although faculty do not leave their jobs due to the increased commute time,[39] estimating with an unbalanced panel could confound our results due to university-level changes over time being reflected in a change in teacher mix over time. Column 2 of Table 5 shows estimates from a balanced panel using teacher and academic-year fixed effects. The results are very close to our preferred estimates reproduced in Column 1.

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[36] This could also bias our results if "other" courses were primarily taught by teachers with low or high commute-cost sensitivity and also primarily located at either the main or satellite campus. We have no means to check for this possibility. It is unnecessary to allocate "other" courses to a class level for before-after estimation because all undergraduate courses were taught at the main campus before and all at the satellite campus after the transition.

[37] Including a third-order time trend is equivalent to including academic year fixed effects because the model is fully saturated.

[38] This is calculated using the midpoint method, a decrease of 52.7 "class hours" per year, and an average of 249.0 annual "class hours" prior to the transition. The percentage change in commute time or distance is 200% since there was zero commute before the transition.

[39] We found no evidence of faculty quitting due to the increased commute. Leaving is costly – tenure-track faculty would have to break a three-year contract with huge financial penalties if untenured or give up secure employment if tenured – and faculty could relocate to subsidized housing at the satellite campus once it opened in 2010.

Columns 3 and 4 test whether the reduction in the minimum teaching load in 2005 from 240 to 225 annual "class hours" caused some of the reduction in teaching time. In Column 3 we add a dummy variable set to one in the year 2005 if the teacher's annual "class hours" were close to the threshold (between 240 and 250 annual "class hours" inclusive) in 2004 and zero otherwise. These are the teachers for whom the minimum constraint was most binding in 2004 and therefore should adjust their teaching time the most in 2005. The dummy variable is positive and insignificant while the baseline effect of change in expected commute days is unchanged. This is consistent with reduced teaching time being attributable to increased commute costs rather than the minimum teaching load change. Column 4 widens the definition of "close to the threshold" to 260 "class hours." The results are very similar.

Column 5 tests whether there is a differential effect on teachers who are above the minimum teaching load in the previous year (240 annual "class hours" in 2003 and 2004 and 225 in 2005 through 2007). It is useful to check this subsample because they are less likely to use other activities besides teaching to fulfill their minimum teaching load and we do not observe the change in these. "Class hours" decrease by 0.68 per expected commute day. Expected commute days increase by an average of 25.7 days per transition year for this subsample, implying a decrease of 17.4 annual "class hours" per transition year or 69.5 annual "class hours" from the full transition. This is above the estimate from the full sample; however, the effects are similar in percentage terms – 17.7% (the sub-sample averages 393.9 annual "class hours" pre-transition) versus 21.2% for the full sample.

Teachers were paid more for larger classes on a sliding scale.[40] An increase in commute time makes teaching larger classes with a higher "hourly" wage more appealing than without a commute. A larger class potentially entails more time than a smaller class (e.g., grading and answering emails) but these tasks can be performed at the main campus. Therefore, teaching a larger class allows a teacher to spread the same commute time over a higher wage. We adjust "class hours" by the wage multiple to obtain "paid hours." For example, if a large class is paid at a 1.5 rate then one "class hour" is equal to 1.5 "paid hours." Column 6 estimates the effect of the transition on annual "paid hours." The results do not reflect a shift toward larger, higher-paying classes after the transition. Annual "paid hours" decrease by 0.78. Given commute days increase by an average of 16.7 days per transition year over four years this implies a cumulative effect of 51.9 annual "paid hours" (19.3% of the 269.4 pre-transition average) "paid hours" – very close to the "class hours" results.

Although the scope for avoidance is limited, teachers with high commute-cost sensitivity may try harder to change their schedule to avoid teaching freshman-level classes after the transition is announced in 2003 and before it begins in 2004. Before-after estimates using Equation (8) with annual undergraduate "class hours" as the dependent variable serve as a check on this because avoidance behavior is impossible once the full transition is complete (Appendix D contains summary statistics for the before-after sample). Column 1 of Table 6 estimates including teacher and academic-year fixed effects $(g_i(t) = \alpha_i + \sum_t \rho_t I_t)$ to control for time-invariant unobserved

[40] For class sizes below sixty a teacher was paid the per-"class hour" wage. For class sizes between 60 and 120 the per-"class hour" wage was multiplied by (1 + (class size – 60)/100) so that each additional student increased the wage by 1%. For class sizes above 120 the per-"class hour" wage was multiplied by 1.6.

teacher preferences for work time and time-varying unobserved factors.[41] The omitted years are 2003 and 2007 so that "after transition" captures the change in teaching time between these two years. Annual "class hours" decline by 56.3 due to the transition. This model corresponds most closely to our preferred DD model. The estimate is only slightly above the DD estimate of 52.7 suggesting that the endogeneity bias toward zero is small or equivalently that it is difficult for faculty to substitute away from teaching class levels that transition earlier. An individual teacher's desire to work may change over time due to promotions, changes in research productivity, changing financial conditions, or changes in the attractiveness of outside options. To accommodate time-varying individual characteristics, we add an asymmetric, quadratic teacher-specific time trend to a balanced-panel regression ($g_i(t) = (1-D_t)\sum_{l=1}^{2}\gamma_{il}^{B}(t-2003)^l + D_t\sum_{l=1}^{2}\gamma_{il}^{A}(t-2007)^l$ where γ_{il}^{B} and γ_{il}^{A} are vectors of parameters to be estimated). The results in Column 2 are not statistically different from Column 1.

Alternative Explanations: Any confounding factors that would bias our DD results must be correlated with teacher-specific changes in commute days. Unilateral actions by the university to increase class sizes would not confound our DD estimates if they fell equally on all faculty members. Although increased class sizes might require faculty to spend more time preparing outside the classroom, this would be uncorrelated with teacher-specific changes in commute costs and wash out of the DD estimates. More problematic for our estimates is that teachers who face large commute time increases may face greater pressure from administrators to teach larger classes because few faculty will tolerate commuting. Larger classes may require more outside preparation time and this may lead teachers with larger commute time increases to further reduce their in-class teaching time leading to a bias away from zero. We show this more formally in Appendix E by extending our theoretical model to allow effort to depend on class size in addition to "class hours."

At the aggregate level, average class size at the satellite campus does exceed that at the main campus during the transition years (71.0 versus 63.0 significant at the 1% level) consistent with faculty wishing to avoid commuting. However, even if the larger class sizes at the satellite campus required more outside preparation time this would bias our DD estimates only if class sizes increased more for those who commuted more. Otherwise, they are differenced out. To examine whether this is the case we regressed expected change in commute days on actual change in class size at the teacher-year level. They are significantly correlated but the impact is small: each additional expected commute day increases class size by 0.07 students. An average annual increase of 16.7 expected commute days over four transition years implies a class size increase of 4.7 students from the full transition. This is only 9.1% of the total increase in class size of 51.8 students between 2003 and 2007. Thus, most of the class size increase should be differenced out in our DD estimates.

To see if this is the case we re-estimate our preferred model controlling for each teacher's change in average class size from the previous year (Column 7 of Table 5). The baseline effect of class size changes is insignificant and the estimated effect of

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[41] This is identical to a fully-saturated model with asymmetric time trends before and after the transition (i.e., 3rd-order time trend before and 2nd-order time trend after). The minimum teaching load change during the transition may confound our before-after estimates. We estimated using a subsample of faculty that exceeded the pre-transition minimum and found very similar results.

commute time on teaching time is almost unchanged. This suggests that the small correlation between class size changes and increased commute costs at the teacher level is not confounding our results. The next two subsections provide additional evidence consistent with commute time as the cause of decreased teaching time by testing theoretical predictions for annual teaching days and daily "class hours."

Annual Undergraduate Teaching Days: The middle panel of Table 4 shows DD estimates of Equation (7) for annual undergraduate teaching days. Our preferred specification with academic-year and teacher fixed effects in Column 2 shows a decrease of 0.26 annual teaching days for each additional expected commute day in a transition year. The estimate is somewhat larger than without controlling for time-specific unobservables (Column 1) and is robust to replacing academic-year dummies with a time trend (Columns 3 and 4). Grossing this up in the same way as for annual "class hours" implies a decrease of 17.7 annual teaching days from the full transition or 22.1% of the pre-transition 79.8 annual teaching days. The middle portion of Table 6 shows the corresponding before-after estimates. Column 3 shows a drop of 27.2 annual teaching days. This is above our DD estimate consistent with some endogeneity bias toward zero in the DD estimate. Controlling for a teacher-specific time trend (Column 4) produces similar results.

Daily Undergraduate "Class Hours": The bottom panel of Table 4 shows the DD estimates of Equation (7) for daily undergraduate "class hours." The preferred specification in Column 2 shows an increase of 0.0023 daily "class hours" for each additional expected commute day in a transition year. These estimates are significant although less so than for the other two work time measures. Grossing up these changes over the full transition yields an increase of 0.16 daily "class hours" or 5.2% of the pre-transition average of 3.0 daily "class hours." The right portion of Table 6 shows the corresponding before-after estimates. Column 5 shows that daily "class hours" increase by 0.49 due to the transition with academic-year fixed effects. This is above our DD estimate of 0.16 "class hours" consistent with a bias toward zero in the DD estimates. These results confirm the theoretical predictions of Section 3. Annual teaching days decrease and daily "class hours" increase consistent with a longer commute imposing higher daily fixed costs.

The estimates of annual "class hours," daily "class hours," and annual teaching days are internally consistent asymptotically using a balanced panel and assuming the stochastic error is independent of the independent variables. It is useful to check the internal consistency of our preferred results to see how far they depart from this ideal. Teachers taught 3.5 daily "class hours" and 84.3 annual teaching days in 2003. Calculating (daily "class hours" in 2003 + estimated change in daily "class hours")*(annual teaching days in 2003 + estimated change in annual teaching days) – (daily "class hours" in 2003)*(annual teaching days in 2003) yields a decrease of 51.1 "class hours" which is close to our estimate of 52.7.

Teachers averaged 79.8 annual undergraduate teaching days before the transition. Given a daily round-trip commute time of 1 to 1.5 hours, this would require 79.8 to 119.7 commute hours per year after the transition. We estimate teachers decreased annual "class hours" by 52.7 in response to this implying that they value commute time at 44 to 66% of their "hourly" wage.[42] Multiplying by the wage, the average teacher would pay RMB 40 – 59 (USD 6.2 – 9.4)[43] to avoid one commute hour given their year 2011 "hourly" wage of RMB 90 (USD 14.2). Put differently, faculty on average dislike undergraduate teaching more than commuting and would prefer 1.5 to 2.3 hours commuting to one "class hour" teaching. This is consistent with greater dis-amenity from undergraduate teaching than commuting (Becker, 1965).

Shirking could increase as a substitute for leisure time lost to longer commutes.[44] Such effects are likely small in our setting given that teachers work in front of a class. Longer commute times can also increase absenteeism (Gutierrez-i-Puigarnau and van Ommeren, 2010b) but in this case teachers must make up any missed classes.

Role of Demographics: Table 7 examines the role of faculty demographics in the response of annual undergraduate "class hours" to commute time. Column 1 allows for a differential effect of the transition by gender and finds no significant difference. This result contrasts with previous evidence that female work time is more sensitive to commute costs.[45] Column 2 controls for rank (assistant professor is omitted). Outside options to undergraduate teaching may differ with position. Graduate courses are usually taught by associate or full professors, full professors are the only faculty rank legally allowed to supervise Ph.D. theses, and senior faculty has greater consulting opportunities. The transition has a similar effect across all ranks.

It is possible that we find no significant difference by gender because a disproportionate fraction of senior faculty are male and the increased bargaining power that conveys offsets higher commute cost sensitivity among female faculty. Interacting rank and gender (Column 3) reveals that male full professors are relatively unaffected by the transition while all other rank-gender combinations experience a similar significant decrease.[46]

Possible University Responses: How did the university accommodate the decrease in per-teacher undergraduate teaching time? We cannot precisely answer this question but we offer some evidence based on the annual demand for and supply of undergraduate student "class hours:"

(9a) $Demand = (Number\ of\ Students) * (Student\ "Class\ Hours"/Student),$
(9b) $Supply = (Number\ of\ Teachers) * (Teacher\ "Class\ Hours"/Teacher) * (Class\ Size).$

[42] Many studies estimate the value of commute relative to work time. These only estimate the equilibrium trade-off and do not provide structural parameters for evaluating transport policy or labor market outcomes (Gibbons and Machin, 2006, p. 7). This literature has yielded a large range for the tradeoff: from 0.2 to 3 times the wage rate (Calfee and Winston, 1998; Small, 1992; Timothy and Wheaton, 2001, Small and Verhoef, 2007). Gibbons and Machin (2006) place the center of these estimates at 0.5.
[43] Throughout the paper we use an exchange rate as of August 2012: 6.35 USD:RMB.
[44] Ross and Zenou (2008) find evidence for this among highly-supervised blue-collar workers.
[45] Blau and Kahn (2007) provide evidence of significant female labor supply changes but also conclude that female labor supply characteristics converge toward those of males over time. Black, Kolesnikova, and Taylor (2014) find that female work time is more sensitive to commute costs as an equilibrium outcome. White (1986) finds evidence that male and female commute times respond differently to income, home ownership, and presence of children.
[46] Using the same specification as in Column 3 we also tested for demographic differences in annual teaching days and daily "class hours." We found no significant differences in either across the different groups.

There are four possible margins of adjustment which are not mutually exclusive. The university could reduce demand for teaching time by: 1) admitting fewer students or 2) reducing the number of student "class hours" required per student; or it could increase supply by: 3) hiring more teachers or 4) increasing class sizes.[47] In Appendix F we approximate these margins of adjustment by taking differentials of Equations (9a) and (9b) and evaluating the changes using the average of 2003 (just before the transition) and 2007 (just after the transition) data.

Demand for undergraduate teaching time increased by 2.84 million student "class hours" between 2003 and 2007. A large increase in the student body increased demand by 3.32 million student "class hours" which was offset by 0.48 million due to an aggregate decline in student "class hours" per student. Given such a large increase in demand, the university was likely encouraging faculty to teach more rather than applying pressure for them to teach less or effectively demoting them by reducing their teaching time and therefore wages.

Increasing the faculty size increased the supply of teaching time by 2.97 million student "class hours" between 2003 and 2007.[48] However, decreased teaching time per faculty member decreased aggregate supply by 6.02 million student "class hours." Therefore, without accounting for class size changes, supply decreased by 3.05 million student "class hours" annually and demand exceeded supply by 5.89 million. This excess was met by a dramatic increase in class size. The university increased the average number of students per class by 51.9 students between 2003 and 2007. Thus, preparation time outside of class likely increased on average for all faculty. However, as the estimates in Column 7 of Table 5 show this was orthogonal to the impact of commute time on teaching time as the DD estimates are almost unchanged when controlling for changes in class size.

Graduate Teaching and Research Output: The top panel of Table 8 presents estimates from a DD specification using Equation (7) with change in annual graduate "class hours" as the dependent variable and expected commute days based on undergraduate teaching as the explanatory variable. Although there is a positive and significant relationship without any controls (Column 1), the estimates are not significant with academic-year fixed effects (Column 2). Expected commute days increase by an average of 12.1 per transition year for this sample. Using the results without fixed effects, this implies an increase of 1.5 annual graduate "class hours" per transition year or 6.1 annual "class hours" cumulatively over the four transition years (a 5.8% increase over the pre-transition average of 104.9). Since 206 teachers are involved in graduate teaching in 2003, this implies a total increase of 1,254 annual "class hours." Undergraduate teaching fell by 52.7 "class hours" per teacher and 536 teachers are involved in undergraduate teaching in 2003 for a total decrease of 28,234 annual "class hours." Therefore, substitution toward graduate teaching represents only about 4.4% of the decrease in undergraduate teaching time.

[47] The number of teachers, students, and student "class hours" per student are clearly determined by the university. Teachers indirectly influence class size through their teaching quality and class requirements; however, the equilibrium effects are determined university-wide.

[48] Temporary and adjunct faculty played a tiny role in the university's response – the teacher-course observations we dropped for them numbered only 109 over the ten years.

We estimate the effect on annual research output using a DD specification based on first differences during the transition:

$$(10)\ \Delta Y_{it} = f_i(t) + \tilde{\beta}\left(\cup_{c\in Q} Tr_{t-1}^{c} CD_{it-2}^{c} - \cup_{c\in Q} Tr_{t-2}^{c} CD_{it-3}^{c}\right) + \Delta UT_{it-1} + \Delta GT_{it-1} + \Delta\varepsilon_{it};\ t \in \{05,06,07\},$$ [49]

where Y_{it} is a measure of annual research output (total publications, top publications, and non-top publications) per teacher and $(f(t) = \alpha_i + \sum_t \rho_t I_t)$ captures teacher-specific linear trends in unobserved factors affecting research output and time-varying unobserved factors affecting research output common to all teachers. This specification exploits individual variation in commute time to explain individual research output. Therefore, to bias the results any confounding factors must be correlated with commute time and research productivity at the individual level. A teacher is included in this sample if they taught undergraduates in at least two contiguous years and produce a research paper in at least one of the transition years. We impose the latter restriction to focus on the sub-sample of faculty actively engaged in research.

We control separately for the lagged change in undergraduate (ΔUT_{it-1}) and graduate (ΔGT_{it-1}) "class hours" taught by teacher i. Faculty heavily involved in undergraduate teaching may have insufficient time to actively research. Graduate teaching time might either detract from research because it takes time otherwise available for research or enhance research if there are sufficient synergies. We lag these changes and the change in expected commute time by one year since we estimate it takes about one year to write and publish a paper in a Chinese journal and 96.5% of the publications in our sample appear in such journals.

The results are shown in the bottom panel of Table 8. Commuting appears to "crowd out" research. This could be caused by increased fatigue or more juggling of tasks due to interruptions from commuting (Coviello, Ichino, and Persico, 2015). Columns 1 and 2 show results for total publications for all faculty members without and with teacher fixed effects $(f_i(t) = \alpha_i)$. Controlling for teacher-specific unobservables increases the effects somewhat. Using the results with both teacher and academic-year fixed effects, each additional expected commute day reduces publications produced a year later by 0.0026. The average expected change in commute days in this subsample is 16.1 days implying a marginal effect of -0.04 annual publications. Cumulatively over the four transition years this implies a decrease of 0.17 publications or 16.8% of the 1.01 average publications pre-transition. Columns 3 and 4 repeat the same specifications for top publications and Columns 5 and 6 for non-top. The total effect is derived from the impact on publications in non-top journals.

7. Conclusion and Discussion

There is little evidence about the causal effect of commute costs on labor supply. The few available results are subject to endogeneity, imprecise measures of commute costs, or lack of comparability in predicting out of sample. Subject to these caveats, previous results indicate a small or no change in labor supply from commute costs

[49] Since we allow teaching time to affect research we would ideally estimate research output and teaching time jointly using a seemingly-unrelated regression (SUR); however, this does not allow us to include fixed effects.

changes. We find that teaching time drops significantly in response to an exogenous increase in commute time. We estimate the commute distance elasticity of work time is -0.12 which is more than ten times larger than previous estimates. As workers in our sample have great flexibility we regard this as representative of workers with flexible work time (e.g., knowledge workers) and an upper bound on more constrained workers. Vis-à-vis the previous literature, our results suggest caution in concluding that work time responds little to commute costs.

Our results suggest that cost-benefit analyses of transportation design should include labor supply responses to changes in commute costs. Similarly, evaluations of policies alleviating traffic congestion such as driving restrictions, staggered work hours, and reversible lanes should include the resulting work time changes. It has been suggested that congestion taxes replace income taxes because the former reduces the negative externalities from driving even though both distort labor supply.[50] Our results imply that faster commutes under a congestion tax will offset some of the labor market distortion arising from monetary commute costs. Our results also have ramifications for theoretical labor supply models. Some assume that work days are fixed and daily hours chosen (Cogan, 1981) while others assume the opposite (Parry and Bento, 2001). We find that both margins adjust.

Our results imply a role for commute time in the long-run level and rate of city growth. Longer commutes will directly negatively impact a city's productivity especially as it concerns attracting high human capital or knowledge workers. The presence of knowledge spillovers in the workplace (Fu, 2007; Rosenthal and Strange, 2008) implies that productivity growth would also suffer from less workplace time. This is particularly relevant given the longer commute times caused by urban sprawl (Brueckner, 2001). The competition between "edge" and core cities will also be affected by the decreased work time of those who commute between the two (Henderson and Mitra, 1993).

Those with flexible work time (to which our estimates are most relevant) exert an outsized effect on the economy. The self-employed, especially entrepreneurs, create positive employment spillovers (van Praag and Versloot, 2008). Their work time and these spillovers are affected by longer commutes (Viard and Fu, 2015). Florida (2004) argues that a "creative class," about thirty percent of the U.S. workforce, sets their own hours and is critical to development of post-industrial U.S. cities. High human-capital and high-technology workers often have flexible schedules and exert a multiplier effect on local employment due to increased demand for local goods and services (Moretti, 2010; Moretti and Thulin, 2013). City growth is particularly sensitive to the presence of high human-capital workers due to spillovers from knowledge sharing (Jovanovic, 1992 and Glaeser, 2003).

For businesses, our results suggest that locating close to employees or easing their commutes can yield more time at work and likely higher productivity (Gutiérrez-i-Puigarnau and van Ommeren, 2010b; Ross and Zenou, 2008). Firms must compensate workers who have longer commutes with higher wages (Timothy and Wheaton, 2001; Fu and Ross, 2013) suggesting an added benefit for a firm in shortening commutes.

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[50] Parry and Bento 2001; De Borger and van Dender, 2003; and Mayeres and Proost, 2001 discuss endogenizing work time in theoretical models analyzing the welfare implications.

Our results have important implications for the expansion of higher education in China. Total undergraduate enrollment in China increased from 2.0 million in 1998 to 8.7 million in 2010.[51] The number of universities has not kept pace leading to higher enrollments: about 14,000 students per university in 2006 compared to 4,000 in 1997. Universities have accommodated this expansion by increasing campus sizes – often by adding satellite campuses. As of 2009, more than sixty universities had established satellite campuses.[52] Use of satellite campuses will lead to reduced teaching supply which, unless compensated for with a larger faculty, will reduce faculty-student interaction and diminish educational quality (Angrist and Lavy, 1999; Arias and Walker, 2004; DeGiorgi, Pellizzari, and Woolston, 2012).

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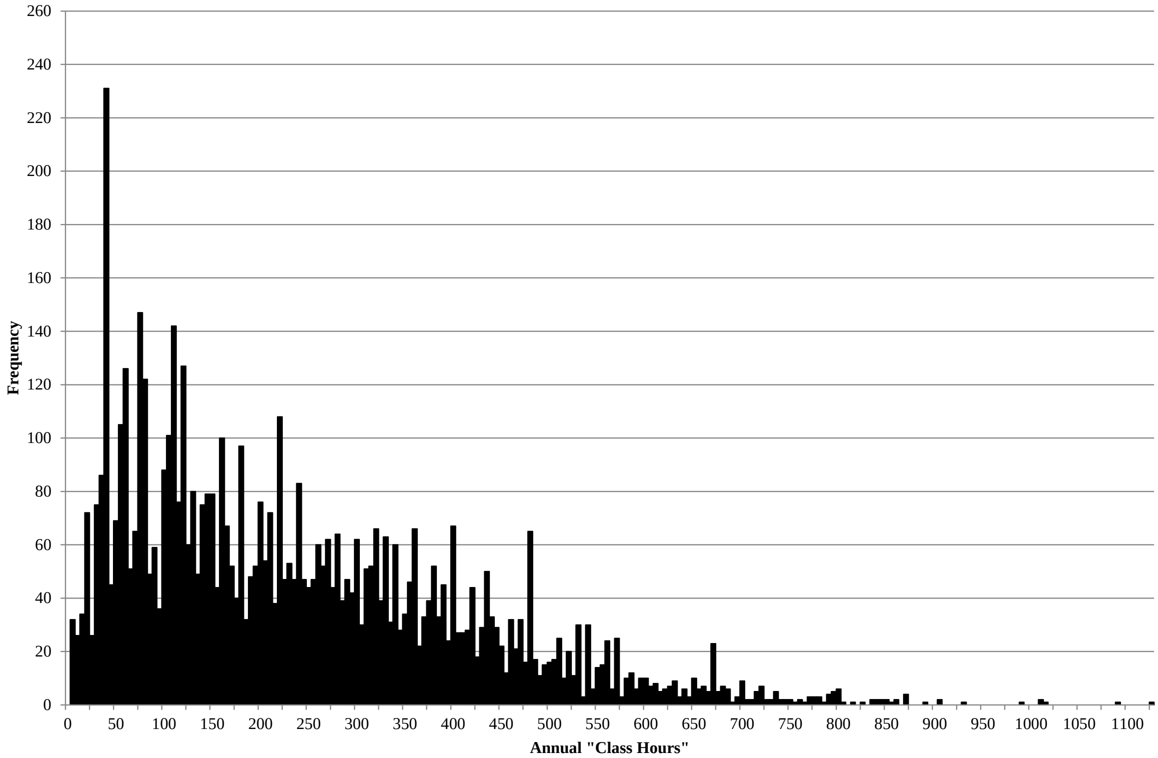
Figure 1 Distribution of Annual Undergraduate “Class Hours” Across All Faculty and Years (2001 to 2009) (N = 6,068)



Annual undergraduate “class hours” for all faculty members in all years of the sample (2001 to 2009). An observation is a faculty member-year combination. Class hours range from 2 to 1,121.

Table 1 Year-to-Year Change in Freshman and Sophomore Annual “Class Hours” as Fraction of Total Annual Undergraduate “Class Hours” by Teacher for Teachers Present in Contiguous Years

		2001	2002	2003	2004	2005	2006	2007	2008	2009
All Teachers										
Freshman	Mean	-0.0074	0.0047	-0.0221	-0.0232	0.0166	0.0199	-0.0269 *	-0.0061	0.0068
	St. Dev.	(0.0188)	(0.0184)	(0.0188)	(0.0179)	(0.0173)	(0.0163)	(0.0161)	(0.0147)	(0.0115)
	N	394	441	452	490	505	525	549	634	709
Sophomore	Mean	0.0080	-0.0085	0.0197	-0.0311	-0.0089	-0.0266	0.0265 *	0.0246 *	-0.0028
	St. Dev.	(0.0201)	(0.0183)	(0.0192)	(0.0191)	(0.0175)	(0.0166)	(0.0160)	(0.0140)	(0.0124)
	N	394	441	452	490	505	525	549	634	709
Excluding "Zeros"										
Freshman	Mean	-0.0131	0.0081	-0.0384	-0.0416	0.0290	0.0314	-0.0430 *	-0.0105	0.0129
	St. Dev.	(0.0331)	(0.0319)	(0.0326)	(0.0322)	(0.0301)	(0.0256)	(0.0258)	(0.0253)	(0.0218)
	N	224	255	260	273	290	333	343	369	375
Sophomore	Mean	0.0125	-0.0134	0.0297	-0.0482	-0.0155	-0.0484	0.0453 *	0.0408 *	-0.0048
	St. Dev.	(0.0315)	(0.0290)	(0.0289)	(0.0296)	(0.0308)	(0.0302)	(0.0273)	(0.0233)	(0.0207)
	N	251	278	300	316	288	289	321	382	424

Mean and standard deviation of change from previous year in freshman or sophomore annual "class hours" as fraction of total annual undergraduate "class hours" across all teachers present in that year and the previous year. The top panel calculates changes for all teachers present in the two adjacent years. The bottom panel calculates changes excluding teachers who have zero values in both adjacent years. In the top panel N measures the number of teachers present in that and the previous year. In the bottom panel N measures the number of teachers with non-zero teaching hours in at least one of the adjacent years. * indicates the mean ratio is significantly different from zero at the 10% to 5% significance level.

Table 2 Descriptive Statistics – Transition Sample (2004 – 2007)

Variable	N	Mean	Std. Dev.	Min	Max
PANEL A: Undergraduate Teaching; 715 Teachers					
Annual "Class Hours"	2,034	260.89	180.00	2.00	1,121.00
Annual Teaching Days[1]	2,029	67.83	36.05	5.00	196.00
Daily "Class Hours"[1]	2,029	3.67	1.56	0.21	10.00
Change in Expected Commute Days	2,034	16.70	37.69	-132.00	162.00
Change in Annual "Class Hours"	2,034	-6.50	148.65	-981.00	971.00
Change in Annual Teaching Days[1]	2,029	-5.70	36.19	-129.00	134.00
Change in Daily "Class Hours"[1]	2,029	0.17	1.48	-6.20	6.55
Male	2,034	0.59	0.49	0.00	1.00
Position - Assistant Professor	2,034	0.49	0.50	0.00	1.00
Position - Associate Professor	2,034	0.26	0.44	0.00	1.00
Position - Full Professor	2,034	0.16	0.37	0.00	1.00
Annual "Paid Hours"	2,034	287.45	197.97	3.20	1,509.42
Change in Annual "Paid Hours"	2,034	-1.65	167.58	-1,304.62	1,333.77
PANEL B: Graduate Teaching; 275 Teachers					
Change in Expected Commute Days	674	12.08	31.86	-105.00	156.00
Change in Annual "Class Hours"	674	6.96	64.85	-225.00	328.00
PANEL C: Research Output: 771 Teachers					
Change in Lagged Expected Commute Days	1,795	16.10	34.71	-112.00	162.00
Change in Annual Publications	1,795	-0.01	1.55	-9.00	10.00
Change in Annual Top Publications	1,795	0.00	0.18	-2.00	3.00
Change in Annual Non-Top Publications	1,795	-0.01	1.55	-9.00	10.00

Panel A includes data for faculty who teach undergraduates in at least two contiguous years from 2003 to 2007. Panel B includes data for faculty who teach undergraduate students in at least two contiguous years from 2003 to 2007 and graduate students in at least one year. Panel C includes data for any faculty who teach undergraduate or graduate students in at least two contiguous years from 2003 to 2007 and produced a research paper in at least one year. [1] Number of observations for annaul teaching days and daily "class hours" is less than 2,034 because some class-year observations are missing day-of-week information. These are included for annual "class hours" because hours are available even if day of week is not.

Table 3 Undergraduate Classes, Student Enrollments, Faculty Size, “Class Hours,” and Class Size across Academic Years (2000 – 2009)

	1	2	3	4	5	6	7	8	9	10
	# of Classes							Student "Class Hours"		
Academic Year	Class-Level Specific	"Other"[1]	Total	# of Students	# of Teachers[2]	Student-Teacher Ratio	Teacher "Class Hours" (1000s)	Total (millions)	Per Student	Average # Students Per Class
2000	1,448	252	1,700	7,370	413	17.8	72.5	5.76	781	79.5
2001	2,121	265	2,386	8,846	484	18.3	100.6	7.46	843	74.1
2002	2,140	298	2,438	10,415	500	20.8	111.6	7.80	749	70.0
2003	2,517	366	2,883	11,366	536	21.2	131.2	7.87	692	60.0
2004	2,310	398	2,708	12,506	590	21.2	118.1	8.15	652	69.0
2005	2,437	423	2,860	13,692	599	22.9	115.1	8.75	639	76.0
2006	2,793	614	3,407	14,893	653	22.8	117.1	10.90	732	93.0
2007	3,036	457	3,493	16,289	719	22.7	95.7	10.70	657	111.8
2008	3,471	554	4,025	16,201	802	20.2	97.8	11.90	735	121.6
2009	3,066	1,323	4,389	15,910	772	20.6	100.1	12.30	773	122.9

Data on number of students assumes no attrition in enrollment by students over time. Data on classes, student enrollments, and "class hours" from the university's Dean of Undergraduate Education office. Data on number of teachers from the university's Human Resources Department. [1] "Other" classes include university-wide, double degree, and sports classes as described in the text. "Other" classes jump dramatically in 2009 due to the university re-classifying many class-specific courses as "other." [2] Total number of teachers involved in undergraduate teaching.

Table 4 Effect of Change in Expected Commute Days on Change in Undergraduate Annual "Class Hours," Annual Teaching Days, and Daily "Class Hours" during Campus Transition (2004 – 2007)

Annual Undergraduate "Class Hours" (# Teachers = 715, N = 2,034)

	1	2	3	4
Δ Expected Commute Days	-0.60 ***	-0.79 ***	-0.75 ***	-0.79 ***
	(0.13)	(0.13)	(0.14)	(0.13)
Time Trend	None	None	1st	2nd
Teacher Fixed Effects	Yes	Yes	Yes	Yes
Academic-Year Fixed Effects	No	Yes	No	No
R^2	0.207	0.244	0.223	0.241
Prob > F (Time Trend)			0.000	0.000

Annual Undergraduate Teaching Days (# Teachers = 713, N = 2,029)

	1	2	3	4
Δ Expected Commute Days	-0.21 ***	-0.26 ***	-0.26 ***	-0.26 ***
	(0.03)	(0.03)	(0.03)	(0.03)
Time Trend	None	None	1st	2nd
Teacher Fixed Effects	Yes	Yes	Yes	Yes
Academic-Year Fixed Effects	No	Yes	No	No
R^2	0.231	0.260	0.254	0.260
Prob > F (Time Trend)			0.000	0.000

Daily Undergraduate "Class Hours" (# Teachers = 713, N = 2,029)

	1	2	3	4
Δ Expected Commute Days	0.0021 *	0.0023 *	0.0026 **	0.0023 *
	(0.0013)	(0.0013)	(0.0013)	(0.0013)
Time Trend	None	None	1st	2nd
Teacher Fixed Effects	Yes	Yes	Yes	Yes
Academic-Year Fixed Effects	No	Yes	No	No
R^2	0.099	0.257	0.237	0.245
Prob > F (Time Trend)			0.079	0.000

Dependent variable is: change in annual undergraduate "class hours" in top panel, change in annual undergraduate teaching days in middle panel, and change in daily undergraduate "class hours" (conditional on teaching that day) in bottom panel. Standard errors in parentheses. Standard errors allow for clustering within teacher and general heteroskedasticity in all regressions. * = 10% significance, ** = 5% significance, *** = 1% significance. The F-test is the p-value for the joint significance level of the time trend variables.

Table 5 Effect of Change in Expected Commute Days on Change in Undergraduate Annual “Class Hours” and Annual “Paid Hours” during Campus Transition (2004 – 2007) – Robustness Checks

	1	2	3	4	5	6	7
			Close to Minimum Teaching Load				
	Preferred Model	Balanced Panel	240 ≤ 2004 "Class Hours" ≤ 250	240 ≤ 2004 "Class Hours" ≤ 260	Above Minimum Threshold	Annual "Paid Hours"	Control for Δ Class Size
Δ Expected Commute Days	-0.79 ***	-0.72 ***	-0.79 ***	-0.80 ***	-0.68 ***	-0.78 ***	-0.80 ***
	(0.13)	(0.14)	(0.13)	(0.13)	(0.22)	(0.16)	(0.14)
(Close to Threshold)*			77.37	66.23			
(Academic Year 2005)			(68.75)	(56.17)			
Δ Class Size							0.13
							(0.20)
Teacher Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Academic-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Teachers	715	328	715	715	380	715	712
N	2,034	1,312	2,034	2,034	778	2,034	2,028
R^2	0.244	0.124	0.245	0.245	0.442	0.228	0.243

Dependent variable in Columns 1 through 5 and 7 is change in annual undergraduate "class hours" and in Column 6 is change in annual undergraduate "paid hours." Columns 1, 3, 4, 6, and 7 include teachers present in at least two contiguous years from 2003 to 2007. The number of observations in Column 7 differ due to missing class size information for some teachers. Column 2 includes teachers present in all years from 2003 to 2007 and Column 5 includes all teachers present in at least two contiguous years and whose teaching load in the previous year exceeds the minimum teaching load. The variable "Close to Threshold" is set equal to one in Column 3 (4) if the teacher had between 240 and 250 (260) "class hours" inclusive in year 2004 and zero otherwise. Standard errors in parentheses. Standard errors allow for clustering within teacher and general heteroskedasticity in all regressions. * = 10% significance, ** = 5% significance, *** = 1% significance.

Table 6 “Before-After” Estimates (2000 – 2003; 2007 – 2009) of Effect of Campus Transition on Undergraduate Annual “Class Hours,” Annual Teaching Days, and Daily “Class Hours”

	1	2	3	4	5	6
	Annual Undergraduate "Class Hours"		Annual Undergraduate Teaching Days		Daily Undergraduate "Class Hours"	
	Year Fixed Effects	Individual Time Trend	Year Fixed Effects	Individual Time Trend	Year Fixed Effects	Individual Time Trend
After Transition	-56.29 ***	-44.11 ***	-27.24 ***	-28.63 ***	0.49 ***	0.71 ***
	(7.49)	(14.89)	(1.82)	(3.50)	(0.07)	(0.13)
Number of Teachers	1,057	192	1,044	190	1,044	190
Teacher Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Academic-Year Fixed Effects	Yes	No	Yes	No	Yes	No
N	4,226	1,344	4,199	1,330	4,199	1,330
R^2	0.691	0.881	0.620	0.856	0.615	0.882

Dependent variable is: annual undergraduate "class hours" in Columns 1 and 2, annual undergraduate teaching days in Columns 3 and 4, and daily undergraduate "class hours" (conditional on teaching that day) in Columns 5 and 6. Standard errors in parentheses. Standard errors allow for clustering within teacher-transition cell and general heteroskedasticity in all regressions. * = 10% significance, ** = 5% significance, *** = 1% significance. Columns 1, 3, and 5 include teachers present in at least one year either before or after the transition. Columns 2, 4, and 6 include teachers present in all years before and after the transition. Columns 2, 4, and 6 include an asymmetric, quadratic time trend interacted with teacher fixed effects. Number of observations lower for annual teaching days and daily "class hours" due to missing day of week information.

Table 7 Effect of Change in Expected Commute Days on Change in Annual Undergraduate “Class Hours” during Campus Transition (2004 – 2007) – Role of Demographics

	1 Effect of Gender	2 Effect of Position	3 Gender-Position Interaction
Δ Expected Commute Days	-0.8170 ***	-0.8068 ***	-0.9397 ***
	(0.1971)	(0.1705)	(0.2662)
Female*(Δ Expected Commute Days)	0.0615		
	(0.2507)		
Associate Professor*(Δ Expected Commute Days)		-0.0559	
		(0.2903)	
Full Professor*(Δ Expected Commute Days)		0.4907	
		(0.3585)	
Female Assistant Professor*(Δ Expected Commute Days)			0.2684
			(0.3201)
Female Associate Professor*(Δ Expected Commute Days)			0.0074
			(0.4026)
Male Associate Professor*(Δ Expected Commute Days)			0.1436
			(0.4493)
Female Full Professor*(Δ Expected Commute Days)			0.0444
			(0.6061)
Male Full Professor*(Δ Expected Commute Days)			0.7766 *
			(0.4545)
Teacher Fixed Effects	Yes	Yes	Yes
Number of Teachers	715	594	594
Academic-Year Fixed Effects	Yes	Yes	Yes
N	2,034	1,849	1,849
R^2	0.244	0.221	0.222

Dependent variable is change in annual undergraduate "class hours." Standard errors in parentheses. Standard errors allow for clustering within teacher and general heteroskedasticity in all regressions. * = 10% significance, ** = 5% significance, *** = 1% significance. Number of observations for regressions involving position lower due to missing values. All regressions include teacher and academic-year fixed effects.

Table 8 Effect of Change in Expected Commute Days on Change in Annual Graduate "Class Hours" and Annual Research Output during Campus Transition (2004 – 2007)

Annual Graduate "Class Hours" (2004 - 2007)

	1	2	3
Δ Expected Commute Days	0.1260 *	0.0771	0.0227
	(0.0695)	(0.0702)	(0.1143)
Teacher Fixed Effects	No	No	Yes
Academic-Year Fixed Effects	No	Yes	Yes
N	674	674	674
R^2	0.071	0.035	0.272

Annual Research Output (2005 - 2007)

	1	2	3	4	5	6
	Total Publications		Top Publications		Non-Top Publications	
Lagged Δ Expected Commute Days	-0.0020 **	-0.0026 *	0.0000	0.0000	-0.0019 **	-0.0026 *
	(0.0009)	(0.0015)	(0.0001)	(0.0001)	(0.0009)	(0.0015)
Lagged Δ Annual Undergraduate "Class Hours"	-0.0001	-0.0003	0.0000	0.0000	-0.0001	-0.0003
	(0.0002)	(0.0004)	(0.0000)	(0.0000)	(0.0002)	(0.0004)
Lagged Δ Annual Graduate "Class Hours"	0.0000	-0.0004	-0.0002	-0.0002	0.0001	-0.0002
	(0.0010)	(0.0019)	(0.0002)	(0.0004)	(0.0010)	(0.0019)
Teacher Fixed Effects	No	Yes	No	Yes	No	Yes
Academic-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
N	1,795	1,795	1,795	1,795	1,795	1,795
R^2	0.003	0.214	0.004	0.074	0.004	0.213

Dependent variable is change in annual graduate "class hours" in top panel and change in annual research output in bottom panel. Standard errors in parentheses. Standard errors allow for clustering within teacher and general heteroskedasticity in all regressions. * = 10% significance, ** = 5% significance, *** = 1% significance. All columns in top panel include any faculty who teach undergraduate students in at least two contiguous years and teach graduate students in at least one year. All columns in the bottom panel include any faculty who teach undergraduate students in at least two contiguous years and produce a research paper in at least one year.

Online Appendix A Theoretical Results

Effect of Commute Time on Annual Undergraduate Teaching Days

This appendix follows Gutierrez-i-Puigarnau and van Ommeren (2009) with modifications for our setting as described in the main text. The effect of an increase in commute time on annual undergraduate teaching days can be determined by totally differentiating Equation (3) in the main text with respect to commute time allowing annual undergraduate teaching days and daily undergraduate “class hours” to vary

$$\text{(A1)}\ \frac{dD}{dt} = \frac{V_{LC}w^U DH + V_L - \frac{dH}{dT}D\left[V_{CC}\left(w^U\right)^2 H - V_{LC}\left(1+e'(H)+w^U\left(H+t+e(H)\right)\right) - V_{LL}\left(1+e'(H)\right)\left(H+t+e(H)\right)\right]}{V_{CC}\left(w^U H\right)^2 - 2V_{LC}w^U H\left(H+t+e(H)\right) + V_{LL}\left(H+t+e(H)\right)^2}.$$

This is negative since Equation (5) in the main text shows that dH/dt is positive, the first term in the numerator is positive by concavity of the utility function, the term in brackets in the numerator is negative by concavity of the utility function and convexity of the effort function, and the denominator is negative by concavity of the utility function and convexity of the effort function.

Effect of Commute Time on Annual Undergraduate “Class Hours”

The effect of an increase in commute time on annual “class hours” is given by

$$\text{(A2)}\ \frac{d(DH)}{dt} = H\frac{dD}{dt} + D\frac{dH}{dt}.$$

Totally differentiating Equations (2) and (3) from the main text and allowing daily undergraduate “class hours” and annual undergraduate teaching days to adjust to a change in commute time

$$\text{(A3a)}\ \frac{dH}{dt} = \frac{\begin{vmatrix} \frac{-\partial F_H}{\partial t} & \frac{\partial F_H}{\partial D} \\ \frac{-\partial F_D}{\partial t} & \frac{\partial F_D}{\partial D} \end{vmatrix}}{|Hessian|},$$

$$\text{(A3b)}\ \frac{dD}{dt} = \frac{\begin{vmatrix} \frac{\partial F_H}{\partial H} & \frac{-\partial F_H}{\partial t} \\ \frac{\partial F_D}{\partial H} & \frac{-\partial F_D}{\partial t} \end{vmatrix}}{|Hessian|}.$$

A local maximum requires that the Hessian be negative definite

$$\text{(A4)}\ \frac{\partial F_H}{\partial H} < 0, \text{ and}$$

$$\text{(A5)}\ |Hessian| = \frac{\partial F_H}{\partial H}\frac{\partial F_D}{\partial D} - \frac{\partial F_H}{\partial D}\frac{\partial F_D}{\partial H} > 0.$$

Given Equations (A2) and (A5)

$$\text{(A6)}\ sign\left[\frac{d(DH)}{dt}\right] = sign\left[H\left(\frac{\partial F_D}{\partial H}\frac{\partial F_H}{\partial t} - \frac{\partial F_H}{\partial H}\frac{\partial F_D}{\partial t}\right) + D\left(\frac{\partial F_H}{\partial D}\frac{\partial F_D}{\partial t} - \frac{\partial F_D}{\partial D}\frac{\partial F_H}{\partial t}\right)\right],$$

where:

$$\text{(A7a)}\ \partial F_H/\partial H = V_{CC}(w^U D)^2 - 2V_{LC}w^U D^2\left(1+e'(H)\right) + V_{LL}D^2\left(1+e'(H)\right)^2 - V_L De''(H),$$

$$\text{(A7b)}\ \partial F_D/\partial H = \partial F_H/\partial D = V_{CC}(w^U)^2 DH - V_{LC}w^U D\left[H\left(1+e'(H)\right) + \left(H+t+e(H)\right)\right] + V_{LL}D\left(1+e'(H)\right)\left(H+t+e(H)\right),$$

$$\text{(A7c)}\ \partial F_D/\partial D = V_{CC}(w^U H)^2 - 2V_{LC}w^U H\left(H+t+e(H)\right) + V_{LL}\left(H+t+e(H)\right)^2,$$

and:

(A8a) $\partial F_H/\partial t = -V_{LC}w^U D^2 + V_{LL}D^2\big(1 + e'(H)\big)$,

(A8b) $\partial F_D/\partial t = -V_{LC}w^U DH + V_{LL}D\big(H + t + e(H)\big) - V_L$.

We now consider two cases of the model to illustrate that it is possible for annual undergraduate "class hours" to either decrease (Case 1) or increase (Case 2).

Case 1: To show that $d(DH)/dt$ can be negative consider $V_{LC} = 0$ and $V_{LL} \approx 0$ (close to zero). Then

(A9a) $\partial F_H/\partial H \approx V_{CC}(w^U D)^2 - V_L De''(H)$,

(A9b) $\partial F_D/\partial H \approx \partial F_H/\partial D = V_{CC}(w^U)^2 DH$

(A9c) $\partial F_D/\partial D \approx V_{CC}(w^U H)^2$,

and

(A10a) $\partial F_H/\partial t \approx 0$,

(A10b) $\partial F_D/\partial t \approx -V_L$.

In this case

(A11) $sign\left[\frac{d(DH)}{dt}\right] = sign[-V_L^2 DHe''(H)]$,

which is negative.

Case 2: To show that $d(DH)/dt$ can be positive consider $V_{LC} = 0$, $V_{CC} \approx 0$ (close to zero) and $e''(H) \approx 0$ (close to zero). Then

(A12a) $\partial F_H/\partial H \approx V_{LL}D^2\big(1 + e'(H)\big)^2$,

(A12b) $\partial F_D/\partial H \approx \partial F_H/\partial D = V_{LL}D\big(1 + e'(H)\big)\big(H + t + e(H)\big)$,

(A12c) $\partial F_D/\partial D \approx V_{LL}\big(H + t + e(H)\big)^2$,

and

(A13a) $\partial F_H/\partial t = V_{LL}D^2\big(1 + e'(H)\big)$,

(A13b) $\partial F_D/\partial t = V_{LL}D\big(H + t + e(H)\big) - V_L$.

In this case

(A14) $sign\left[\frac{d(DH)}{dt}\right] = sign\big[-V_{LL}V_L D^2\big(1 + e'(H)\big)\big(t + e(H) - He'(H)\big)\big]$.

which is positive as long as long as effort costs do not increase too quickly: $e'(H) < \frac{t+e(H)}{H}$.

Online Appendix B Theoretical Models with Two Activities

A Model with Undergraduate Teaching and Research Time

We modify the model in Appendix A to consider two activities (undergraduate teaching and research) with only one of the activities (undergraduate teaching) affected by commute time. To keep the analysis manageable we collapse the choices of annual undergraduate teaching days and daily undergraduate "class hours" into a single choice of annual undergraduate "class hours" for each activity. A teacher's annual utility after substituting out the budget and time constraints (Equation (1) in the main text) is now

(B1) $v = V\big(Y + F + B(T^R) + w^U T^U, \bar{T} - T^U(1+t) - T^R - e(T^U + \gamma T^R)\big)$,

where $\gamma > 0$ allows a research hour to affect effort differentially from a teaching hour. The two first-order conditions are now

(B2) $F_U \equiv \frac{\partial v}{\partial T^U} = V_C w^U - V_L\big(1 + t + e'(T^U + \gamma T^R)\big) = 0$, and
(B3) $F_R \equiv \frac{\partial v}{\partial T^R} = V_C B'(T^R) - V_L\big(1 + \gamma e'(T^U + \gamma T^R)\big) = 0$.

Equation (B2) says that the marginal utility of consumption from an extra undergraduate "class hour" equals the foregone marginal utility of leisure including the effect of fatigue and commute time. Equation (B3) says that the marginal utility from an extra hour of research time equals the foregone utility of leisure including the effect of fatigue.

A local maximum requires that the Hessian be negative definite

(B4) $\frac{\partial F_U}{\partial T_U} < 0$, and
(B5) $|Hessian| = \frac{\partial F_U}{\partial T^U}\frac{\partial F_R}{\partial T^R} - \frac{\partial F_U}{\partial T^R}\frac{\partial F_R}{\partial T^U} > 0$.

Combining Equations (B2) and (B3) the optimally chosen work times fulfill

(B6) $\frac{w^U}{B'(T^R)} = \frac{1+t+e'(T^U+\gamma T^R)}{1+\gamma e'(T^U+\gamma T^R)}$.

The teacher equates the ratio of the marginal return to undergraduate teaching (the wage) and research (the marginal increase in annual bonus) to the ratio of the foregone marginal utility of leisure due to undergraduate teaching and research time. To see how time spent on undergraduate teaching and research depends on the commute time we apply the implicit function theorem and totally differentiate Equations (B2) and (B3) letting undergraduate teaching and research time adjust to a change in commute time

(B7a) $\frac{dT^U}{dt} = \frac{\begin{vmatrix} \frac{-\partial F_U}{\partial t} & \frac{\partial F_U}{\partial T^R} \\ \frac{-\partial F_R}{\partial t} & \frac{\partial F_R}{\partial T^R} \end{vmatrix}}{|Hessian|}$,
(B7b) $\frac{dT^R}{dt} = \frac{\begin{vmatrix} \frac{\partial F_U}{\partial T^U} & \frac{-\partial F_U}{\partial t} \\ \frac{\partial F_R}{\partial T^U} & \frac{-\partial F_R}{\partial t} \end{vmatrix}}{|Hessian|}$.

Now

(B8a) $\frac{\partial F_U}{\partial t} = -V_{CL}T^U w^U + V_{LL}T^U[1 + t + e'(T^U + \gamma T^R)] - V_L < 0$,
(B8b) $\frac{\partial F_R}{\partial t} = -V_{CL}T^U B'(T^R) + V_{LL}T^U[1 + \gamma e'(T^U + \gamma T^R)] < 0$.

And

(B9a) $\frac{\partial F_U}{\partial T^U} = V_{CC}(w^U)^2 - 2V_{LC}w^U[1 + t + e'] + V_{LL}[1 + t + e']^2 - V_L e'' < 0$, (B9b) $\frac{\partial F_R}{\partial T^R} = V_{CC}(B')^2 - 2V_{LC}B'[1+\gamma e'] + V_{LL}[1+\gamma e']^2 + V_C B'' - V_L \gamma^2 e'' < 0,$

(B9c) $\frac{\partial F_U}{\partial T^R} = \frac{\partial F_R}{\partial T^U} = V_{CC}w^U B' - V_{LC}B'[1+t+e'] - V_{LC}w^U[1+\gamma e'] + V_{LL}[1+\gamma e'][1+t+e'] - V_L \gamma e'' < 0,$

where we suppress the arguments of e and B for clarity. We now consider two cases of the model to illustrate that even though undergraduate teaching time decreases in commute time it is possible for research time to either increase (Case 1) or decrease (Case 2) depending on the relative effect of research and undergraduate teaching time on effort (*i.e.*, the magnitude of γ).

Case 1: Suppose $V_{CL} = 0$, $V_{CC} \approx 0$ (close to zero), $B''(T^R) = 0$, and $\gamma > 1$ then

(B10a) $\frac{\partial F_U}{\partial t} \approx V_{LL}T^U\big(1+t+e'(T^U+\gamma T^R)\big) - V_L,$

(B10b) $\frac{\partial F_R}{\partial t} \approx V_{LL}T^U\big(1+\gamma e'(T^U)\big).$

And

(B11a) $\frac{\partial F_U}{\partial T^U} \approx V_{LL}\big(1+t+e'(T^U+\gamma T^R)\big)^2 - V_L e''(T^U+\gamma T^R),$

(B11b) $\frac{\partial F_R}{\partial T^R} \approx V_{LL}\big(1+\gamma e'(T^U+\gamma T^R)\big)^2 - V_L \gamma^2 e''(T^U+\gamma T^R),$

(B11c) $\frac{\partial F_R}{\partial T^U} = \frac{\partial F_U}{\partial T^R} \approx V_{LL}\big(1+\gamma e'(T^U+\gamma T^R)\big)\big(1+t+e'(T^U+\gamma T^R)\big) - V_L \gamma e''(T^U+\gamma T^R).$

It can be verified that parameter values exist for which the second-order condition is met. Now

(B12a) $\frac{dT^U}{dt} \approx \frac{V_L V_{LL} T^U \gamma e''(T^U+\gamma T^R)(\gamma-1+\gamma t) + V_L V_{LL}\left(1+\gamma e'(T^U+\gamma T^R)\right)^2 - (V_L)^2\gamma^2 e''(T^U+\gamma T^R)}{|Hessian|} < 0,$

(B12b) $\frac{dT^R}{dt} \approx \frac{V_L V_{LL} T^U e''(T^U+\gamma T^R)(1-\gamma-\gamma t) - V_L V_{LL}\left(1+\gamma e'(T^U+\gamma T^R)\right)\left(1+t+e'(T^U+\gamma T^R)\right) + \left(V^L\right)^2 \gamma e''(T^U+\gamma T^R)}{|Hessian|} > 0.$

The second and third terms in the numerator of Equation (B12a) are negative. Given that $\gamma > 1$ the first term in the numerator is also negative and undergraduate teaching time decreases with commute time. The second and third terms in the numerator of Equation (B12b) are positive. Given that $\gamma > 1$ the first term in the numerator is also positive and research time increases in commute time. Therefore, undergraduate teaching time decreases with commute time, while research time increases with commute time. Relatively little time is spent on research because research effort costs are high and highly convex ($\gamma > 1$). This implies a relatively large amount of leisure time. Therefore, as commute time causes the teacher to scale back undergraduate teaching time some of this is replaced with research time.

Case 2: Suppose $V_{CL} = 0$, $V_{CC} \approx 0$ (close to zero), $B''(T^R) = 0$, and $\gamma \approx 0$ (close to zero) then

(B13a) $\frac{\partial F_U}{\partial t} \approx V_{LL}T^U\big(1+t+e'(T^U)\big) - V_L,$

(B13b) $\frac{\partial F_R}{\partial t} \approx V_{LL}T^U.$

And

(B14a) $\frac{\partial F_U}{\partial T^U} \approx V_{LL}\big(1+t+e'(T^U)\big)^2 - V_L e''(T^U),$

(B14b) $\frac{\partial F_R}{\partial T^R} \approx V_{LL},$

(B14c) $\frac{\partial F_R}{\partial T^U} = \frac{\partial F_U}{\partial T^R} \approx V_{LL}\big(1+t+e'(T^U)\big).$

It can be verified that the second-order condition is met for all parameter values. Now

(B15a) $\frac{dT^U}{dt} \approx \frac{V_L V_{LL}}{|Hessian|} < 0,$
(B15b) $\frac{dT^R}{dt} \approx \frac{V_L V_{LL}\left(T^U e''(T^U) - 1 - t - e'(T^U)\right)}{|Hessian|}.$

If $e''(T^U)$ is sufficiently large relative to t/T^U and $e'(T^U)/T^U$ then research time decreases with commute time. In this case, undergraduate teaching time and research time both decrease with commute time. Significant time is spent on research because research effort costs are low and increase slowly ($\gamma \approx 0$). This implies a relatively small amount of available leisure time. Therefore, as commute time increases the leisure time of the teacher is further squeezed. Since the marginal returns to research are so low it is optimal to free up leisure time by decreasing research time.

A Model with Undergraduate and Graduate Teaching Time

A model with undergraduate and graduate teaching time is isomorphic to a model with undergraduate teaching and research time. This can be seen by making the following substitutions in the above model

$T^R = T^G$ and
$B(T^G) = w^G T^G$;

where T^G is the time spent on graduate teaching, w^G is the wage for graduate teaching, and γ now allows for different levels of effort for graduate relative to undergraduate teaching. Note that we have eliminated the dependence of the annual salary on research output.

Since $B'(T^G) = w^G > 0$ and $B''(T^G) = 0 \le 0$ the results from the model above all follow. Also since $w^G = 1.5w^U$, Equation (B6) implies

(B16) $\gamma = 1.5 + \frac{0.5+1.5t}{e'(T^U+\gamma T^G)} > 1.5.$

Therefore this corresponds to Case 1 above and undergraduate teaching declines in commute time while graduate teaching increases.

Online Appendix C Econometric Model with Heterogeneous Teachers

Consider a model with teacher-specific commute cost sensitivity:

(C1) $Y_{it} = \alpha_i + g_i(t) + \tilde{\beta}_i\left[\bigcup_{c\in Q}(Tr_t^c CD_{it-1}^c)\right] + X_{it} + \tilde{\varepsilon}_{it}.$

$\tilde{\beta}_i$ captures the effect of increased commute time on teaching time for teacher i. $\tilde{\varepsilon}_{it} \sim N(0, \sigma_\varepsilon^2)$ is an error distributed independently across teachers and years. Assume that commute-cost sensitivity across teachers is $\tilde{\beta}_i = \tilde{\beta} + \sigma_{i\beta}$ with $\sigma_{i\beta} \sim N(0, \sigma_\beta^2)$ independently across teachers and independent of $\tilde{\varepsilon}_{it}$. This heterogeneity occurs because teachers have different schedules for non-teaching activities or family situations such as number of dependents.

DD Model: Focusing on the transition years (2004 to 2007) and taking first differences of Equation (C1):

(C2) $\Delta Y_{it} = f_i(t) + \tilde{\beta}\left(\bigcup_{c\in Q} Tr_t^c CD_{it-1}^c - \bigcup_{c\in Q} Tr_{t-1}^c CD_{it-2}^c\right) + \Delta\varepsilon_{it};\ t = 04, \dots, 07,$

The error is $\Delta\varepsilon_{it} = \Delta\tilde{\varepsilon}_{it} + \sigma_{i\beta}\left(\bigcup_{c\in Q} CD_{it-1}^c - \bigcup_{c\in Q} CD_{it-2}^c\right)$. The second term arises because $\tilde{\beta}$ contains a random component across individuals. This random component is scaled up or down by the change in commute days. The covariance structure in Equation (C2) can be accommodated by clustering standard errors by teacher and allowing for heteroskedasticity:

(C3a) $E\left[\,\Delta\,\varepsilon_{it}|CD_{it-1}^{c},CD_{it-2}^{c}\right]=0,$
(C3b) $E\left[\,\Delta\,\varepsilon_{it}^{2}|CD_{it-1}^{c},CD_{it-2}^{c}\right]=\left(\bigcup_{c\in Q}Tr_{t}^{c}CD_{it-1}^{c}-\bigcup_{c\in Q}Tr_{t-1}^{c}CD_{it-2}^{c}\right)^{2}\sigma_{\beta}^{2}+2\sigma_{\varepsilon}^{2}$
(C3c) $E\left[\,\Delta\,\varepsilon_{it}\,\Delta\,\varepsilon_{is}|CD_{it-1}^{c},CD_{it-2}^{c},CD_{is-1}^{c},CD_{is-2}^{c}\right]=$
$\left(\bigcup_{c\in Q}Tr_{t}^{c}CD_{it-1}^{c}-\bigcup_{c\in Q}Tr_{t-1}^{c}CD_{it-2}^{c}\right)\left(\bigcup_{c\in Q}Tr_{s}^{c}CD_{is-1}^{c}-\bigcup_{c\in Q}Tr_{s-1}^{c}CD_{is-2}^{c}\right)\sigma_{\beta}^{2}\ ,t\neq s$
(C3d) $E\left[\,\Delta\,\varepsilon_{it}\,\Delta\,\varepsilon_{js}\middle|CD_{it-1}^{c},CD_{it-2}^{c},CD_{js-1}^{c},CD_{js-2}^{c}\right]=0,i\neq j,\forall s,t.$

Before-After Model: In our before-after model we use the "before" and "after" years:

(C4) $Y_{it}=\alpha_{i}+g_{i}(t)+\tilde{\beta}_{i}[D_{t}\times CD_{it-1}^{To}]+X_{it}+\tilde{\varepsilon}_{it};\ t\in\{00,\dots,03;07,\dots,09\},$

where $CD_{it}^{To}=\bigcup_{c\in Q}CD_{it}^{c}$ is total commute days in year t across all class levels and $D_{t}=Tr_{t}^{Fr}\times Tr_{t}^{So}\times Tr_{t}^{Ju}\times Tr_{t}^{Se}$ is a dummy variable equal to one after all class levels have transitioned ($t\in\{07,\dots,09\}$) and zero before ($t\in\{00,\dots,03\}$). To avoid relying on a lagged measure of commute days and the associated measurement noise we transform Equation (C4) to measure an average effect of commute days on the outcome variable:

(C5) $Y_{it}=\alpha_{i}+g_{i}(t)+\beta D_{t}+X_{it}+\varepsilon_{it};\ t\in\{00,\dots,03;07,\dots,09\}.$

Given our assumption that $\tilde{\beta}_{i}$ is uncorrelated with $CD_{it}^{To}\ \forall t\in\{01,\dots,09\}$, $\beta=\tilde{\beta}\overline{CD}^{To}$ where $\overline{CD}^{To}=\frac{1}{3}\sum_{t=07}^{09}\frac{1}{I}\sum_{I}CD_{it}^{To}$ is the average number of commute days across all teachers and years after completion of the transition (2007 – 2009). It captures the average effect across all teachers on the outcome variable Y_{it} of moving all class levels to the satellite campus. The error structure of Equation (C5) is:

(C6a) $E[\varepsilon_{it}|D_{t}]=0$
(C6b) $E[\varepsilon_{it}^{2}|D_{t}]=D_{t}(\overline{CD}^{To})^{2}\sigma_{\beta}^{2}+\sigma_{\varepsilon}^{2}$
(C6c) $E[\varepsilon_{it}\varepsilon_{is}|D_{t},D_{s}]=[1+D_{t}D_{s}((\overline{CD}^{To})^{2}-1)]\sigma_{\beta}^{2}\ ,t\neq s$
(C6d) $E\left[\varepsilon_{it}\varepsilon_{js}|D_{t},D_{s}\right]=0,i\neq j,\forall s,t.$

This can be accommodated by clustering standard errors in cells defined by a teacher before versus after the transition and allowing for heteroskedasticity.

Online Appendix D Descriptive Statistics for 1,057 Teachers Involved in Undergraduate Teaching Before or After the Transition (2000 – 2003; 2007 – 2009)

Variable	N	Mean	Std. Dev.	Min	Max
Annual "Class Hours"	4,226	233.81	169.68	2.00	1,088.00
Annual Teaching Days[1]	4,199	65.49	38.68	3.00	196.00
Daily "Class Hours"[1]	4,199	3.51	1.48	0.21	9.95
Male	4,226	0.600	0.490	0.000	1.000
Position - Assistant Professor	3,720	0.498	0.500	0.000	1.000
Position - Associate Professor	3,720	0.325	0.469	0.000	1.000
Position - Full Professor	3,720	0.177	0.381	0.000	1.000

An observation is a teacher-year combination. Includes data for any faculty who teach at least one undergraduate class either before or after the transition. [1] Number of observations for annual teaching days and daily "class hours" is less than 4,226 because some observations are missing day-of-week information.

Online Appendix E Model with Effort as Function of Class Size and Daily Undergraduate "Class Hours"

Suppose effort is a function of both daily undergraduate "class hours" and class size: $e(H,S)$. Further, assume that effort is increasing and convex in both class size and daily "class hours" and that teaching a larger class increases marginal fatigue from daily "class hours." That is

(E1) $\frac{\partial e}{\partial H} > 0$, $\frac{\partial^2 e}{\partial H^2} > 0$, $\frac{\partial e}{\partial S} > 0$, $\frac{\partial^2 e}{\partial S^2} > 0$, and $\frac{\partial^2 e}{\partial H \partial S} > 0$.

A simple effort function that satisfies these conditions is: $e(H,S) = a + bSH + cS^2H^2$.

Using Equation (4) in the text we can solve for daily "class hours:"

(E2) $H = \frac{1}{S}\left(\frac{t+a}{c}\right)^{1/2}$. Note that:

(E3) $\frac{\partial H}{\partial S} = -\frac{1}{S^2}\left(\frac{t+a}{c}\right)^{1/2} < 0$.

Thus, if the university unilaterally adjusts class size upward as it transitions to the satellite campus this will decrease undergraduate teaching time irrespective of the increase in commute time. This is absorbed by the academic-year fixed effects in the DD estimates although they would confound the before-after estimates.

Moreover, those with larger class sizes will reduce their daily undergraduate "class hours" by more in response to an increase in commute time:

(E4) $\frac{\partial^2 H}{\partial t \partial S} = -\frac{1}{2cS^2}\left(\frac{t+a}{c}\right)^{-1/2} < 0$.

Since this would confound the DD estimates if the effects are significant we control for class size in Column 7 of Table 5.

Online Appendix F Quantifying University's Response to Decreased Undergraduate Teaching Time

Taking differentials of the supply and demand of undergraduate student "class hours" (Equations (9a) and (9b) in the main text):

(F1a) $\Delta\, Demand =$
$\Delta\,(Number\ of\ Students) * \overline{(Student\ "Class\ Hours"/Student)} + \overline{(Number\ of\ Students)} * \Delta\,(Student\ "Class\ Hours"/Student)$,

(F1b) $\Delta\, Supply = \Delta\,(Number\ of\ Teachers) * \overline{(Teacher\ "Class\ Hours"/Teacher)} * \overline{(Class\ Size)} + \overline{(Number\ of\ Teachers)} * \Delta\,(Teacher\ "Class\ Hours"/Teacher) * \overline{(Class\ Size)} + \overline{(Number\ of\ Teachers} * \overline{(Teacher\ "Class\ Hours"/Teacher)} * \Delta\,(Class\ Size)$,

where bars indicate averages of values in 2003 and 2007. We can approximate the adjustment margins on the demand side using Equation (F1a) and the data in Table 3. The number of students increased 4,923 between 2003 and 2007.[1] Multiplying by the average student "class hours" per student (674.5) implies

[1] Table 3 assumes that student attrition rates are zero. While we do not have annual attrition data, it appears to be quite low. For example, 2,598 students were admitted in academic year 2000 and 2,586 graduated four years later implying an attrition rate of 0.5%. Similarly, 2,750 students were admitted in academic year 2001 and 2,718 graduated four years later implying an attrition rate of 1.2%.

annual demand for teaching time increased by 3.32 million student “class hours.” Student “class hours” per student declined from 692 in 2003 to 657 in 2007. Multiplying by the average number of students (13,827.5), demand decreased by 0.48 million student “class hours” annually. The net increase in demand between 2003 and 2007 was therefore 2.84 million student “class hours” annually.

We can similarly approximate the adjustment margins on the supply side using Equation (F1b) and the data in Table 3. The number of teachers increased 183 between 2003 and 2007. Multiplying by the average teacher “class hours” per teacher (188.9) and average class size (85.9), this increased annual supply of teaching time by 2.97 million student “class hours.” Teacher “class hours” per faculty member declined by 111.7. This decreased supply by 6.02 million student “class hours” given the average number of teachers (627.5) and average class size (85.9). Therefore, without accounting for class size changes, supply decreased by 3.05 million student “class hours” and demand exceeded supply by 5.89 million student “class hours.” This excess was met by a dramatic increase in class size. The university increased average class size by 51.9 students per class between 2003 and 2007. This increased supply by 6.15 million student “class hours” given the average number of teachers (627.5) and average teacher “class hours” per teacher (188.9).[2]

[2] This is 0.27 million student “class hours” higher than the shortfall because the differentials involve large changes and we approximate the change point by the average value before versus after the change.