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Involuntary and Voluntary Cost Increases in Private Research Universities

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Abstract

We consider involuntary and voluntary cost increases in Carnegie I and II private research universities, where we find that voluntary cost increases are over three times as high as involuntary cost increases. As is the case with public research universities, private universities economized on the use of tenure track faculty and non-professional staff, while they invested heavily in more executive/managerial and professional staff from 1987 to 2008. Also as is the case with public research universities, private universities began across the board cost reductions by reducing *all* staff/student ratios and shifted resources out of overhead and into academic spending from 2008 to 2011. Further, the privates accelerated their cost saving use of faculty and non-professional staff relative to the reductions in executive/managerial and professional staff such that the ratio of tenure track faculty to full time nonacademic professional staff continued to decline.

1 Introduction.

In this paper we use the same cost model for Carnegie I and II *private* research universities as we did in our earlier analysis of *public* research universities (Martin and Hill, 2013). Let the *publics* and the *privates* refer to these two types of research universities in what follows. In the public university paper, we found at least $2 in voluntary cost increases for every $1 in involuntary cost increases, while the ratio among the privates is at least $3 in voluntary cost increases for every $1 in involuntary cost increases.

Other than higher cost per student in the privates, the staffing pattern results prove quite similar. Both types of institution economized on the use of faculty and non-professional staff from 1987 to 2008, while investing heavily in nonacademic professional staff members. Nonacademic professional staff refers to the sum of executive/managerial staff and other professional staff. Furthermore, the privates, as did the publics, began across the board cost cutting after 2008 and shifted resources out of overhead and into academics[1] after 2008.

These results suggest decisions taken within higher education are responsible for most of the cost increases observed over the past three decades, rather than being due to external cost drivers such as government mandates or Baumol’s cost disease. The results are most consistent with Bowen’s rule (1980). Therefore, higher education cost increases are not inevitable; they are within each institution’s control.

The paper is organized as follows. In the next section, we briefly discuss the four traditional drivers of higher education cost and in the third section we consider the simple algebra of labor cost per student. The data is presented in the fourth section, the estimation results in the fifth section, the cost deconstruction in the sixth section, and the results are summarized in the final section.

2 Internal and external cost drivers.

The four traditional cost drivers can be sorted according to their origin. The external cost drivers are government mandates (regulation) and Baumol’s cost disease. Since the academy is imbedded in the macro-economy, it follows that external effects must have an impact on higher education cost. When government imposes regulation on higher education, those regulations raise cost. We call the external cost drivers the “involuntary cost increases.”

The most important involuntary cost increase is Baumol’s cost disease. Real wages increase as productivity improves in the macro-economy, while service sector productivity improves slowly or not at all. In order to retain productive employees, service industries must pay higher real wages even though productivity does not improve. Baumol’s cost disease rests on rising real wages/benefits in the macro-economy and *constant* or

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[1] Academic expenditures are the sum of expenditures for teaching, research, and public service and overhead is expenditures in all other categories. The shifts after 2008 are significant and cannot be explained by changes in staffing.

slowly *increasing* productivity in higher education. Thus, Baumol's cost disease implies constant or slow improvements in productivity and real wages that follow real wage changes in the macro-economy.

In fact, staff productivity *declined* from 1987 to 2008 as the private universities increased their staff/student ratios significantly. Further, from 2008 to 2011 real wages in private higher education continued to *rise* at their previous rates even as real wages in the macro-economy *fell*.

The two internal cost drivers are bundling services not previously supplied by higher education and Bowen's rule (1980). We call the two internal cost drivers the "voluntary cost increases," since they represent decisions taken by these institutions that must raise costs. Bundling services can be efficient[2]; but it can also be anticompetitive when it facilitates price discrimination[3] or acts as a barrier to competition[4] from less well funded institutions (Martin, 2011). Bundling tactics tend to accelerate the "facilities arms race" and this has implications for public policy concerning subsidized student loans. Since the amount the student borrows depends on the price of attendance and bundling consumption with education adds to the price of attendance, current student loan policy subsidizes consumption. A substantial part of outstanding student loan debt is incurred to purchase consumption goods rather than just investments in education.

Bowen's rule states that universities raise all the money they can and spend all the money they raise on an unlimited list of projects that seemingly enhance "quality" (1980). The short version of Bowen's rule is "revenue drives cost." The revenue theory of cost rests on the balanced budget financial model, the peculiar economics of experience goods, and unresolved agency problems (Martin, 2011). The higher education financial model means revenues cap expenditures and cost cannot go up without raising the revenue cap; hence, universities are constantly in fund raising mode.

Reputations dominate competition only when consumers are uncertain about quality. If quality is known, reputations are irrelevant and the more uncertain consumers are the more important reputations become. Reputations are the focal point of academic competition and these markets are efficient under four conditions[5]; unfortunately, none of those conditions are satisfied in higher education. Inefficiency in an experience good

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[2] Bundling can enhance consumer welfare when there are positive externalities in either production or consumption. Positive externalities in production lead to lower costs and externalities in consumption lead to greater utility when the bundled goods are consumed together than when they are consumed separately.

[3] Cable companies bundle television channels in order to extract more revenue per customer than they would receive if they allowed consumers to choose their own bundles.

[4] When the university bundles luxury goods with the provision of basic higher education services it raises the cost of competition to lower ranked schools that may not be able to afford such luxury goods. Further, bundling entertainment services with education tends to confuse the student's perception of the education benefits received.

[5] The four conditions are: when the consumer purchases the service frequently, they can evaluate quality immediately after purchase, they abandon quality cheaters immediately, and there are only two parties to the transaction.

market leads to a "market for lemons" (Akerlof, 1970) risk, where quality unravels over time. Further, quality uncertainty creates perverse incentives; since consumers associate price with quality (Chivas Regal effect), the more the university spends the higher is its perceived quality. Worse still, institutions do not compete on the basis of cost since consumers associate that tactic with low quality; competition for reputation does not lead to competition based on cost.

Bowen considers periods when cost per student declined (the Great Depression and the 1970's) and when cost rose briskly (the post WW II growth period). He argues universities behave differently when resources are plentiful than they do when they are scarce (Bowen, 1980, 29-47), we call these periods "loose revenue" and "tight revenue" periods. The differences illustrate how tight revenue caps and loose revenue caps alter behavior; Bowen describes this as the "revenue theory of cost" (1980, 15).

Finally, universities are lightly regulated when compared to for-profit firms, face little scrutiny from the press, there are no third party groups with a financial interest in monitoring university behavior, governance is not contestable, and governing boards do not have to stand for reelection. The only natural constraint on agency abuse is shared governance and that has deteriorated substantially over the past three decades.

The combination of balanced budget financial models, experience goods, weak agency control, and the economics of bundling create an environment where rent taking is likely. Reduced effort is the easiest way to extract rents in any institutional environment and rising staff/student ratios are one indicator of rent taking by reduced effort. Unfortunately, rising staff/student ratios are also consistent with greater investment in quality; so, "reductions in productivity" may be investments in quality and/or rent taking.

3 Staffing patterns, cost, and quality.

The algebra of labor cost per student is simple and direct, whether one considers the total university or academic department. By definition labor cost (wages/benefits) per student is

$$labor \equiv w \times (s / e) \ ,$$

where w is average labor cost per staff member, s is the number of staff members, and e is the number of students. Clearly, (s/e) is the staff/student ratio for the university or department.

Other things equal, labor cost per student must rise if either real wages/benefits or the staff/student ratio increases. Alternatively, labor cost per student must decline if the staff/student ratio declines or the real wage declines. If the real wage increases and the proportion of total cost attributable to labor declines, it means labor productivity has improved. In the macro-economy, real wages tend to increase when labor productivity improves; the tendency in higher education for real wages to rise as productivity declines is an anomaly.

Interpreting labor cost per unit is ambiguous, since quality is unobserved. If w goes up cost per student must rise, but the increase in w may be the result of hiring/rewarding more productive employees. Similarly, if s/e goes up cost must rise, but increases in staff to student ratios may represent an investment in higher quality.

Hence, changes in either *w* or *s/e* may represent investments in quality. Alternatively, increases in *w* may be driven by institutional politics rather than market forces and increases in *s/e* may be driven by rent collection through reduced effort. Therefore, labor cost per student may be rising due to either improved quality, rent seeking behavior, or some combination of the two.

In 1987, labor costs were 47 percent of total cost at private universities and 55 percent of total cost in public universities. By 2010, labor costs were 57 percent of total cost at private universities and 61 percent of total cost at public universities[6]. Hence, the labor component of total cost increased at both public and private universities from 1987 to 2010, although the size of the increase, both in percentages and dollars, was larger at private universities. These increases in labor cost suggest the privates and publics may have invested heavily in quality improvement from 1987 to 2010.

If all increases in labor cost per student were investments in quality, the 60 private universities and the 146 public universities could be investing $20 and $32 billion each year in higher quality by 2010. Over the 23 year interval to 2010, these investments would sum to over one half trillion dollars. These are significant sums.

Assume all increases in *w* and in *s/e* represent investments in quality. If those investments are effective there must be evidence of improved quality[7]. At this point, no one has made a credible case that three decades of higher *w* and higher *s/e* resulted in quality improvements. Indeed, most of the evidence suggests the quality of undergraduate education is in secular decline[8]; completion rates declined, grade inflation increased, students spend less time studying, adult numeracy/literacy rates declined, and critical thinking skills did not improve[9]. Finally, the unraveling of quality in an inefficient experience good market is a core prediction from the "market for lemons" problem (Akerlof, 1970). This suggests either these enormous investments in higher quality failed to improve quality or at least some of the increases in *w* and *s/e* are due to agency problems.

4 The Data.

The data are drawn from the IPEDS website and cover 1987, 1989, 1991, 1999, 2002, 2005, 2008, 2010, and 2011. For each year, there are 60 Carnegie I and II private research universities; due to errors in reporting,

[6] Since private cost per student is twice as large as public cost per student, the higher share of labor cost at publics reveals much higher dollar value of non-labor cost per student at the private institutions. This is consistent with a much larger investment in facilities at private institutions.

[7] The cost/benefit analysis would also have to be positive if the investment is sound.

[8] A secular decline in quality is what experience good theory and the market for lemons suggests (Akerlof, 1970) (Martin, 2011).

[9] See (Arum and Josipa, 2011) (Bok, 2005) (Hersch and Merrow, 2005) (Massy, 2003).

not all of these observations are useable. In total, there are 506 usable observations[10] in the estimating sample[11], for an average of 56 each year. All dollar denominated variables are measured in constant 2008 dollars and the average values are weighted by FTE enrollment.

The variables. In the interest of comparison, we employ the same variables in this study as we did in our analysis of public research universities (Martin and Hill, 2013). A complete variable list along with definitions is contained in Figure 1. Weighted average values for the variables for 1987, 2008, and 2011 are contained in Table 1. The last two columns in Table 1 contain the average annual growth rates for the following intervals, respectively: 1987 to 2008 and 2008 to 2011.

The interval from 1987 to 2008 is the "loose revenue" period where economic conditions were good and the public placed increasing value on higher education each year. The "tight revenue" period is covered by the intervals from 2008 to 2011, where unemployment is high and more questions are being asked about cost and return on investment in higher education. Bowen argues cost per student tends to rise under loose revenue constraints and decline under tight revenue constraints (1980, 29-47). Cost per student did not decline at either the publics or the privates from 2008 to 2010, but it did among the privates from 2010 to 2011. Total cost per student also declined by 4.5 percent per year from 2008 to 2011 at private liberal arts colleges.

Loose Revenue Constraints. From 1987 to 2008, real academic costs at private research universities grew at an average annual rate of 3.1 percent, while real overhead cost per student grew by 2.0 percent per year. The privates began the period with overhead cost per student higher than academic cost and ended the period with academic cost higher than overhead cost. The academic share increased throughout the period. Real total cost per student increased by about 50 percent from 1987 to 2008. The privates' cost per student is approximately twice as high as it is at public universities. By contrast, the publics' overhead cost grew faster than academic costs causing the academic share to decline.

Total enrollment at both types of institution grew steadily, although the publics are almost twice as large as the privates in terms of total enrollment. The most significant difference with respect to enrollment at the two types of institutions is the growth in their graduate programs: both graduate programs grew significantly during the period (the publics by almost 2 percent per year and the privates by 6 percent per year); but, the privates'

[10] Given 60 private universities the potential number of observations for nine years is 540; however, the average cost per student at Cal Tech and Rockefeller University was at or above $1 million, while the next highest cost per student from the other 58 universities was approximately $275 thousand. Being about four times as high, costs per student at these two universities are outliers; hence, they were deleted. Within the remaining 58 universities, there were 16 observations with missing values.

[11] There are two samples in this analysis. The estimating sample contains 506 observations. Since the institutions in the beginning and ending periods for the cost decomposition sample must be the same, there are only 495 observations (55 universities) in the cost decomposition sample.

graduate programs more than doubled. The privates began the period with smaller graduate programs on average than the publics and ended the period with larger graduate programs; hence, on average the privates captured a greater share of the "graduate student market." It is not clear what might have happened to the quality adjusted market share; however, we do know that the elite privates were increasing their share of the quality adjusted undergraduate market share (Cook and Frank, 1993). The number of part time students declined at both types of institutions.

The FTE faculty ratios per 100 students at the privates are approximately two times as high as at the publics and the growth rate per year from 1987 to 2008 is more than twice as high at the privates. While tenure track faculty staffing ratios at the publics were approximately constant, they grew by 1.1 percent per year at the privates. Each type of institution made more intensive use of contract and part time faculty. While the tenure track faculty to full time nonacademic professional staff member ratio was approximately 1 to1 at the publics in 1987, it was 0.6 to1 at the privates; the privates began the period with 1.7 professional staff members per 1 tenure track faculty member. By 2008, the publics had 1.7 nonacademic professional staff members and the privates had 2.5 nonacademic professional staff members per tenure track faculty.

The FTE nonacademic professional staff member ratio per 100 students at the privates is approximately 85 percent higher than at the publics, while their average annual growth rates from 1987 to 2008 were 2.7 percent and 2.1 percent, respectively. The FTE non-professional staff ratios per 100 students at both types of universities declined by over 1 percent per year; the privates and the publics economized on the use of non-professional staff from 1987 to 2008.

Since many of the staff/student ratios are increasing, it means the average annual growth rates by staff types are considerably higher than the ratio growth rates imply. If r is the staff/student ratio; then, the rate of growth in staff members is the sum of the growth rate in the ratio and the growth rate in students, $g_s = g_r + g_e$. Therefore, the growth rate in tenure track faculty at the privates and publics from 1987 to 2008 were 2.6 and 1.6 respectively and tenure track faculty increased by 55 percent and 34 percent at private and public institutions. Similarly, private and public FTE executives/managers increased by 82 percent and 36 percent at private and public institutions and FTE nonacademic professional staff increased by 82 percent and 84 percent respectively from 1987 to 2008.

At the privates, full professor salaries and their growth rate are consistently higher than at the publics. This is also true for assistant professor salaries and FTE staff salaries at the privates. Generally, the privates pay higher salaries than the publics and those salaries grow faster over time. The real staff-benefit cost per full time employee and their growth rates are approximately the same at both types of institution.

As one would expect, total real operating revenue per student is approximately twice as high at the privates as at the publics; growing at healthy rates of 2.8 and 2.4 percent per year. Although the private revenues per student are higher than the publics, their respective core[12] revenues per student are not that different. The significant differences are in donor, hospital, and other operating revenues; the private revenue sources are considerably higher. There is a discernible trend at the publics toward a greater reliance on fund raising and other revenues. The publics' funding sources look more like the privates each year. Again, the growth in real revenues is much higher than the rates implied by the growth in revenues per student; for example total operating revenue at the privates and publics grew by 90 and 80 percent respectively from 1987 to 2008. These are not paltry increases in real resources.

The 2.4 percent growth rate in real revenues per student at the publics and 2.8 percent at the privates during the loose revenue constraint period made considerably more revenue available to each type of institution every year. The publics and the privates' response to that new revenue were both similar and significantly different. First, both types of institution economized on the use of FTE non-professional staff and they both used contract and part time faculty more intensively. Further, both types of institution invested heavily in more full time nonacademic professional staff members, such that their respective ratios of tenure track faculty to full time nonacademic professional staff members continued to decline. If these institutions were investing heavily in higher academic quality, why would higher academic quality require more full time nonacademic professional staff than tenure track faculty and a steady rise in that difference over time?

The differences are also interesting. First, the privates invested heavily in their FTE faculty, particularly the tenure track faculty, while the publics did not. Graduate programs at both institutions grew but there was an obvious and serious commitment by the privates to larger graduate programs. These graduate programs are the most expensive type of instruction. As a consequence, academic cost per student grew briskly at the privates, while overhead cost grew faster than academic cost at the publics.

On balance, one suspects that tenure track faculty members have more control over resources at privates than they do at the publics. From *The London Times* global university ranking for the top 50 research universities, 30 of those institutions are US universities (15 privates and 15 publics). Within the top 25, 11 are US privates and 4 are US publics. There are 60 private research universities and 146 public research universities in the US. Hence, there is a higher concentration of world class institutions among the privates than among the publics. It follows there is a greater concentration of world class scholars in the privates than in the publics; these scholars have more lucrative employment opportunities than other academics. This is confirmed by the higher faculty salaries at the privates than at the publics. Therefore, private faculty preferences with respect to university

[12] "Core revenues" in both cases is student revenues from tuition, fees, and room/board plus all government appropriations.

resource use must be considered by university administrations. The growth in graduate programs at private universities reflects those preferences.

Tight Revenue Constraints. Over the 2008 to 2010 tight revenue period, total cost continued to increase by 0.4 percent per year at the privates and by 0.5 percent per year at the publics. At the privates and the publics, resources were shifted out of overhead and into academic expenditures; private academic cost per student increased by over 5 percent per year and by over 7 percent at the publics, while overhead decreased by 3.4 percent per year at privates and 6.1 percent per year at publics. The academic shares of total cost exceeded 50 percent at the privates and publics in 2010. For the representative institution in each category, the shifts in cost out of overhead and into academics after 2008 represent a $72 million shift in the privates and a $62 million shift in the publics.

As one might expect during a period of high unemployment, FTE student enrollment and full time graduate enrollment continued to increase, while part time student enrollment continued to decline. At the privates and the publics, contract faculty went up and part time faculty went down. Tenure track faculty went down at both types of institution. FTE nonacademic professional staff members went down at both types of institution, but not as rapidly as did tenure track faculty since the ratio of tenure track to nonacademic professional staff members continued to decline. The declines in FTE non-professional staff accelerated at both types of institution.

Salaries for full professors, assistant professors, and for FTE staff increased at both types of institution; whereas, the increases were considerably higher at the privates. Benefit costs per full time employee continued to increase, despite the high unemployment. From 2008 to 2011, total operating revenue increased by 2.4 percent per year at both types of universities.

The most significant common response among these institutions is the move to across the board staff cutting during the tight revenue period. This differs significantly from the loose revenue period where staff cutting was selective and excluded nonacademic professional staff members. Should the tight revenue period persist, real cost per student may begin to decline as it did during the Great Depression and the 1970's. The data suggests universities are able to improve productivity when the need arises.

5 Cost Model.

For the total cost (*tc*) model we specify the log-linear regression

$$\ln\left(tc_{it}\right) = \beta' x_{it} + \alpha_i + u_{it} \qquad (1)$$

where α_i are individual effects, with $i = 1, \ldots, n$ and $t = 1, \ldots, T_i$. The least squares, random effects and fixed effects parameter estimates are reported in Table 2. The OLS estimates are reported in the first column, random effects estimates[13] in the second column, random effects estimates with robust cluster standard errors in the third column, fixed effects estimates in the fourth column and fixed effects estimates with robust cluster standard errors in the fifth column. For the purpose of "deconstructing costs," and the results in Table 3, the parameters β are estimated using fixed effects since the Hausman test rejects the null hypothesis that the regressors and random effects are uncorrelated in each equation.[14] We employ robust cluster-corrected covariance matrix estimates because some residual correlation across time remains even after including year dummies.[15] We then employ the partial differential approach to quantify the involuntary (Baumol) and voluntary (Bowen) effects in the next section. The same estimation techniques were employed in our public research university paper (Martin and Hill, 2013).

Estimation Results. Results using fixed effects estimation are contained in column (5) of Table 2[16]. The coefficients for *ftestu, ftgrad, ptstu, staffsal, ftenpro, rev, invest,* and *d1989* are statistically significant using a two-tail test at the 0.01 or better level and have the anticipated signs. The coefficients for *ftef, ftenapst, ftenapst2, donor, hosp,* and *other* are statistically significant using a two-tail test at the 0.05 or better level.

The signs for *ttad* and *ttad2* are not significant. The data does not support any of the three variations of the governance hypothesis, since the *ttad* is also insignificant when the model is run without *ttad2*. On the other hand, the signs for *ftef* and *ftenapst* are both positive and significant at better than the .05 level; other things equal, more tenure track faculty and nonacademic professional staff members cause cost per student to rise.

The signs for *ftenapst* and *ftenapst2* suggest total cost is concave in *ftenapst*; total cost per student increases at a decreasing rate as the nonacademic professional staff per 100 student ratio increases. The implied peak value is 35 nonacademic professional staff per 100[17] students; that value is well within the data experience,

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[13] All model estimations are carried out in Stata 12.1

[14] This conclusion was drawn on the basis of the usual contrast tests under the assumption of homoscedasticity (no clustering), and also the regression based Hausman test describe in Wooldridge (2010, 332). In this test the averages of the time varying variables are added as regressors in a random effects estimation and their significance jointly tested based on a cluster corrected covariance matrix. Using not only the complete set of time varying variables, but also various subsets of those variables, we reject the null hypothesis that the heterogeneity is not correlated with the time averages.

[15] The data used are not equally spaced through time. We have data from 1987, 1989, 1991, 1999, 2002, 2005, 2008, 2010, and 2011. For each equation, using the fixed effects residuals, we regress the residuals in time t against the residuals in time $t-1$, both with and without other regressors, for each year. These tests are described in Wooldridge (2010, 310-311). While not every pair of years produced significant evidence of serial correlation, it was significant in more estimations than not. This justifies the use of fixed effects estimation with cluster corrected covariance matrix.

[16] Fixed effects estimates obtained using XTREG, FE in Stata 12.1. Standard errors are based on a cluster corrected covariance matrix, which is used because some significant serial correlation remains even with year dummies.

[17] 95% interval estimate [20.49,48.57]

as the maximum value is 76 per 100. This result is also robust to specification and additional data and is similar to the result obtained for public research universities. The elasticities of total cost at the quartiles of *ftenapst* are 0.091, 0.120, and 0.123, respectively.[18]

In accord with Bowen's revenue theory of cost, total cost is an increasing function of total operating revenue per student from the previous year. The coefficient is positive and the elasticity of cost with respect to the previous year's revenue per student is significant. The coefficient for investment income is negative and significant at the 0.01 level.

6 Cost Analysis.

As in the previous study, we use the differential method to deconstruct cost changes during the loose revenue period (1987 to 2008) and the tight revenue period (2008 to 2011). A detailed description of this methodology is contained in the public research university article (Martin and Hill, 2013). The procedure is to use partial differentials of the semi-log estimation model to deconstruct the actual cost per student changes for each interval. Specifically, the partial differential for the following incremental effects would involve subsets of the independent variables as follows:

1. Program Scale Changes: *ftestu*, *ftgrad*, *ptstu*, *ta*
2. Cost Savings: *cf*, *ptf*, *ftenpro*, *ptnpro*
3. Baumol Benefits: decomposed *benstaff*. The change in Baumol benefits is 62% of the actual change in *benstaff*.
4. Baumol Salaries: decomposed *staffsal*. The change in Baumol salaries is 62% of the actual change in *staffsal*.
5. Bowen Productivity: *ftef*, *ftenapst*, *ftenapst2*, *ptnapst*, *staffsize*
6. Bowen Salaries: decomposed *staffsal*. The change in Bowen salaries is 38% of the actual change in *staffsal*.
7. Bowen Benefits: decomposed *benstaff*. The change in Bowen benefits is 38% of the actual change in *benstaff*.
8. Bowen Governance: *ttad*, *ttad2*.
9. Bowen Revenue: *rev*, *invest*, *donor*, *hosp*, *other*.

Each cost deconstruction is a "forecast" of cost increases within the sample experience; hence, they have forecast confidence intervals.

[18] 95% interval estimates are [0.0004, 0.1806], [−0.0052, 0.2448] and [−0.0493, 0.2953].

The cost deconstruction forecasts for the "loose revenue" period, 1987 to 2008, are contained in Table 3A and the forecasts for the "tight revenue" period, 2008 to 2011, are contained in Table 3B. The actual changes in total cost per student among the private institutions is more than twice as much as in public institutions for both periods and the voluntary/involuntary ratios are over 50 percent higher among the private institutions than among the public institutions for both periods.

Salaries and Benefits. By construction, *staffsal* and *benstaff* depend on staffing patterns and correlation analysis reveals that 38 percent of the variation in each variable can be attributed to changes in the staffing variables. Therefore, we assume 62 percent of the variation in both *staffsal* and *benstaff* is due to external macroeconomic effects and, as a result, are involuntary cost increases; while the remaining 38 percent of their variation is the result of internal decisions and are voluntary cost increases.

Cost Saving. The data in Table 1 reveals private institutions economized on the use of tenure track faculty by employing more contract faculty and more part time faculty. Further, these universities improved the productivity of non-professional staff members over both periods. During the loose constraint period, these cost savings amount to a reduction in cost per student equal to $7,573. During the tight constraint period, the cost savings was a further reduction of $3,829 per student; the reduction in cost over the 3 year period versus the reduction in cost over the earlier 21 year period reflects a more intense effort to reduce cost in the later period.

Scale and Program Effects. There were substantial changes in scale, as measured by enrollment, and changes in program mix, as measured by graduate enrollment, teaching assistants, and part time students during the period from 1987 to 2008. Those changes continued after 2008. Despite the increased cost associated with larger graduate programs and more teaching assistants, the rising undergraduate enrollment and declining part time enrollment led to a net reduction in cost per student of $6,063 during the loose revenue period and $2,081 during the tight revenue period.

Since actual total cost per student increased by $32,022 from 1987 to 2008 and by $4,680 from 2008 to 2011, it is clear the cost reductions achieved through cost saving and program effects were not passed on to students and parents in the form of lower total cost per student. Therefore, the total cost increases that must be accounted for by involuntary and voluntary cost increases are $45,658 per student for the loose revenue period and $11,032 for the tight revenue period.

Involuntary cost increases. Baumol salary and benefits effects are defined to be those changes that cannot be explained by staffing changes within the universities; hence, 62 percent of salary and benefits changes in each interval are Baumol effects. For the loose revenue constraint period, this total is $3,741 and for the tight revenue constraint period the total is $1,063.

Voluntary cost increases. Voluntary cost increases are driven by internal choices taken by each institution; they include salary/benefit effects from staffing changes which accounts for 38 percent of the variation, reductions in productivity due to higher staff/student ratios, governance effects, and revenue effects on total cost. During the loose revenue constraint period, the salary effect was $2,293, the benefit effect was $513, the reduction in productivity effect was $12,376, the governance effect was $535, and the revenue effect was $10,740. During the tight revenue constraint period, the salary effect was $651, the benefit effect was $188, the governance effect was $94, and the revenue effect was $6,430. The significant difference in voluntary cost increases between the loose and tight regimes was the shift to cost cutting among the nonacademic professional staff members where cost per student was lowered by $443.

Overview of Cost Analysis. During the loose revenue period, involuntary cost increases accounted for 10 percent of the total change in cost, while voluntary cost increases accounted for 58 percent of the total change in cost. The resulting voluntary/involuntary ratio is 5.8; for every $1 in involuntary costs there is $5.80 in voluntary cost. The corresponding ratio among public universities is 3.4.

During the tight revenue period, involuntary cost increases accounted for 12 percent of the total change in cost, while voluntary cost increases accounted for 71 percent of the total change in cost. The voluntary/involuntary ratio is 5.4. The corresponding ratio among public universities is 3.8.

If one assumes all salary and benefit effects are involuntary cost increases, the voluntary/involuntary ratio would be 3.2 at the privates; the public ratio was 2.2. In both cases a more favorable assumption about the size of external versus internal effects reveals that internal cost drivers are larger than the external cost drivers by a considerable margin.

The behavior of public and private research universities was essentially the same before 2008 and after 2008. During the loose revenue period, they economized on the use of tenure track faculty and on non-professional staff, while they invested heavily in more nonacademic professional staff members. During the tight revenue period, they began economizing on all staff across the board, although, they economized more intensively on academic staff and non-professional staff than they did on nonacademic professional staff, since the ratio of tenure track faculty to full time nonacademic professional staff members continued to decline.

Furthermore, both the public and private institutions reported significant shifts in resources out of overhead and into academic spending after 2008; however, the cost decompositions reveal that less than one third of what was reported could be explained by overhead staff changes. This suggests shifts in resources between overhead and academics may be re-definitions of spending categories rather than actual movements of resources out of one activity and into another activity. In other words, the data suggests universities are managing their financial reporting in the way for-profit firms “manage their earnings” in order to influence capital markets.

7 Conclusions

Our research suggests two-thirds, or more, of the increase in cost per student at public/private research universities are driven by internal decisions taken by those institutions. Since university cost increases are an outlier with respect to all other sectors in the economy, including healthcare, this conclusion makes intuitive sense. If these costs were driven by external macroeconomic effects, they should be within the norm for the entire economy, rather than the economy's highest outlier. Most of the problem must come from within these universities.

The major cost drivers in higher education are not external to the academy and outside its control; this is good news for reform. Further, the level of real resource per student increased dramatically from 1987 to 2011 at our elite universities. At private research universities, real operating revenues per student increased by 54 percent and at public research universities, real operating revenues per student increased by 57 percent. Real operating revenues among all 60 Carnegie I and II private research universities were over $23 billion higher in 2010 than in 1987 and real operating revenues among all 146 public Carnegie I and II research universities were over $50 billion higher in 2010 than in 1987. The common narrative that higher education suffers from too little support does not fit the facts; this does not mean the distribution of that support is not a problem, however.

In an earlier section, we examined the relationship between real wages/benefits and staff/student ratios on cost per student. Increases in real wages/benefits and staff/student ratios can represent investments in higher academic quality. A careful analysis of staffing patterns at public and private research universities reveals a pattern of choosing least cost academic staff, persistent cost reductions among nonprofessional staff, and heavy investment in more nonacademic professional staff.

Clearly tenure track faculty members are more expensive than contract and part-time faculty. However, academic labor markets are efficient; tenure track faculty members are more expensive because they are better trained and more capable than contract and part time faculty. Contract and part-time faculty start out in the same junior faculty pool as do those who land a tenure track position. Those who land a tenure track position are judged by a competitive process to have superior talent than those who do not get a tenure track position; those who move from tenure track to tenured are also closely evaluated. These processes lead to salaries that reflect academic talent. Therefore, it seems curious, at best, that an institution whose objective is academic excellence would economize on tenure track faculty, while increasing its employment of nonacademic professional staff. Can a university "administer its way to world class status;" or, does the proliferation of overhead follow after high academic status is achieved?

Actions reveal preferences and the forgoing actions seem inconsistent with the hypothesis that universities invested their new resources in academic quality during the 1987 to 2011 period. Further, if these new resources were invested in academic quality, there would be visible returns on investments of this magnitude. We argue the increase in cost, documented staffing decisions, and evidence of decline in quality are consistent with Bowen's rule; or, as it is more commonly known, consistent with "bureaucratic entropy" – the tendency of overhead staff to grow faster than the number of customers served, inevitably leading to higher cost per customer.

This is a governance problem found in every complex organization and there are important incentives in higher education that encourage this behavior (Chivas Regal effect) and few constraints that might mitigate it.

Figure 1
Variable List[ab]

Cost:

Academic cost per student (*ac*) – real instruction, research, and public service cost per student.
Overhead cost per student (*oh*) – real overhead cost per student.
Total cost per student (*tc*) – real total cost per student.
Academic share (*acshare*) – academic cost as a percent of total cost.

Enrollment:

FTE students (*ftestu*) – full time equivalent students.
FT undergraduate students (*ftug*) – full time undergraduate students.
FT graduate students (*ftgrad*) – full time graduate students.
PT students (*ptstu*) – part time students.

Faculty:

Contract faculty (*cf*) – number of contract faculty per 100 students.
PT faculty (ptf) – number of part time faculty per 100 students.
Teaching assistants (*ta*) – number of teaching assistants per 100 students.
Tenure track faculty (*tt*) – number of tenure track faculty per 100 students.
Ratio of tenure track to full time non-academic professional staff (*ttnap*) – tenure track faculty/full time executives and full time professional staff.
FTE faculty (*ftef*) – sum of contract faculty, part time faculty, and tenure track faculty per 100 students.

Staff:

FTE nonacademic professional staff members (*ftenapst*) – sum of FTE executive and FTE professional staff per 100 students.
FTE executives (*fteex*) – FTE executives per 100 students.
FTE professional (*ftepro*) – FTE professional staff per 100 students.
FTE non-professional (*ftenpro*) – FTE non-professional staff per 100 students.
PT non-academic professional staff (*ptnapst*) – part time executives plus part time professional staff members per 100 students.
PT non-professional (*ptnpro*) – part time non-professional staff per 100 students.
Staff size (*staffsize*) – ratio of professional and non-professional staff to FTE executives.

Salaries/Benefits:

Full professor salary (*psal*) – average real full professor salary.
Assistant professor salary (*assprofsal*) – average real assistant professor salary.
Staff salary (*staffsal*) – average real FTE staff salary.
Benefits (*benstaff*) – average real benefits per FT staff member.

Revenue:

Core (*core*) – core revenue per student (tuition/fees, room/board, and all government appropriations).
Donor (*donor*) – private donations and gifts per student.
Hospital (*hosp*) – hospital revenue per student.
Other (*other*) – all other revenue per student, including grants.
Investment income (*invest*) – investment income per student.

[a] All dollar values are in constant 2008 dollars per FTE student.
[b] Staffing ratios are per 100 FTE students.

Table 1
Private Research Universities: Weighted Average Values

Year	1987	2008	2011	87 to 08	08 to 11
Academic Cost	$26,025	$43,012	$49,646	3.1	5.1
Overhead Cost	$36,894	$52,076	$46,698	2.0	-3.4
Total Cost	$62,919	$95,087	$96,344	2.4	0.4
Academic Share	42.10	46.07	52.80	0.4	4.9
Enrollment:					
FTE Students	9516	12536	13242	1.5	1.9
FT Under Grad	7288	9472	9857	1.4	1.4
FT Grad	2603	5895	6564	6.0	3.8
PT Students	2919	1554	1480	-2.2	-1.6
Teaching:					
Contract Faculty	4.3	5.7	6.7	1.6	6.1
PT Faculty	1.2	2.1	1.5	3.9	-8.9
Teach Assist	0.9	2.3	2.3	6.9	0.4
Tenure Track	5.3	6.5	6.2	1.1	-1.7
TT faculty/NA ProStaff	0.6	0.4	0.4	-1.5	-1.0
FTE Faculty	10.6	14.3	14.5	1.7	0.3
Administration:					
FTE NA ProStaff	11.7	18.4	18.1	2.7	-0.6
FTE Exec/Mgr	3.6	5.4	5.3	2.4	-0.6
FTE Pro	8.1	13.0	12.8	2.9	-0.6
FTE Non-Pro	18.8	14.9	13.5	-1.0	-3.1
Staff Size	10.3	7.7	7.7	-1.2	0.0
Salaries/Benefits:					
Full Prof	$108,186	$139,377	$143,464	1.4	1.0
Assistant Prof	$63,209	$81,059	$84,290	1.3	1.3
Staff Salary	$56,477	$83,614	$89,151	2.3	2.2
Benefits	$12,967	$23,550	$26,437	3.9	4.1
Revenue:					
Total Op Rev	$55,602	$88,415	$94,692	2.8	2.4
Core	$22,510	$28,067	$30,038	1.2	2.3
Donor	$5,363	$13,423	$14,056	7.2	1.6
Hospital	$8,738	$14,842	$15,172	3.3	0.7
Other	$18,991	$32,083	$35,427	3.3	3.5
Invest Income	$3,430	$52,851	$44,218	68.6	-5.4
Sample size	55	58	57		

*Average annual growth rates.

Table 2
Cost Equation Estimations

	(1) OLS	(2) RE	(3) RE_ROB	(4) FE	(5) FE_ROB
cf	-0.0247*	-0.0239***	-0.0239*	-0.0192***	-0.0192*
	(0.0138)	(0.0059)	(0.0144)	(0.0053)	(0.0114)
ptf	-0.0177**	-0.0147***	-0.0147**	-0.0108**	-0.0108
	(0.0079)	(0.0056)	(0.0074)	(0.0048)	(0.0070)
ta	0.0071	0.0076	0.0076	-0.0001	-0.0001
	(0.0104)	(0.0056)	(0.0084)	(0.0051)	(0.0068)
ftef	0.0332**	0.0307***	0.0307**	0.0251***	0.0251**
	(0.0128)	(0.0057)	(0.0143)	(0.0050)	(0.0121)
ftestu	-0.0189**	-0.0313***	-0.0313**	-0.0909***	-0.0909***
	(0.0078)	(0.0033)	(0.0155)	(0.0054)	(0.0317)
ftgrad	0.0311*	0.0469***	0.0469*	0.1119***	0.1119***
	(0.0157)	(0.0078)	(0.0261)	(0.0102)	(0.0387)
ptstu	0.0361	0.0579***	0.0579*	0.1070***	0.1070***
	(0.0246)	(0.0116)	(0.0349)	(0.0133)	(0.0399)
ttad	-0.0334	-0.0342	-0.0342	-0.0737	-0.0737
	(0.0946)	(0.0798)	(0.0873)	(0.0709)	(0.0883)
ttad2	0.0001	0.0001	0.0001	0.0130	0.0130
	(0.0173)	(0.0160)	(0.0168)	(0.0139)	(0.0140)
city	-0.0274	-0.0248	-0.0248	.	.
	(0.0369)	(0.0480)	(0.0484)	.	.
rural	-0.1353**	-0.1787*	-0.1787*	.	.
	(0.0625)	(0.0977)	(0.1040)	.	.
carnegie	0.1867***	0.2383***	0.2383***	.	.
	(0.0330)	(0.0432)	(0.0426)	.	.
fwest	-0.1784	-0.1700**	-0.1700	.	.
	(0.1473)	(0.0660)	(0.1609)	.	.
glakes	-0.0220	-0.0495	-0.0495	.	.
	(0.0326)	(0.0445)	(0.0443)	.	.
neweng	-0.0490	-0.0467	-0.0467	.	.
	(0.0298)	(0.0384)	(0.0406)	.	.
stem	0.1011*	0.1293**	0.1293	.	.
	(0.0517)	(0.0516)	(0.0874)	.	.
medical	0.0795**	0.0934**	0.0934**	.	.
	(0.0384)	(0.0435)	(0.0469)	.	.
prof	-0.2142***	-0.2495***	-0.2495***	.	.
	(0.0566)	(0.0583)	(0.0784)	.	.
staffsal	0.0036***	0.0034***	0.0034***	0.0031***	0.0031***
	(0.0008)	(0.0006)	(0.0007)	(0.0005)	(0.0009)
benstaff	0.0069*	0.0055***	0.0055*	0.0017	0.0017
	(0.0035)	(0.0018)	(0.0032)	(0.0016)	(0.0026)
ftenapst	0.0311***	0.0256***	0.0256***	0.0155***	0.0155**
	(0.0078)	(0.0048)	(0.0068)	(0.0045)	(0.0074)
ftenapst2	-0.0005***	-0.0004***	-0.0004***	-0.0002***	-0.0002**
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
ftenpro	0.0142***	0.0144***	0.0144***	0.0113***	0.0113***
	(0.0029)	(0.0017)	(0.0034)	(0.0017)	(0.0031)
ptnapst	-0.0174**	-0.0173	-0.0173**	-0.0147	-0.0147*
	(0.0080)	(0.0114)	(0.0077)	(0.0100)	(0.0080)
ptnpro	-0.0000	0.0034	0.0034	0.0092	0.0092
	(0.0081)	(0.0080)	(0.0079)	(0.0069)	(0.0072)
staffsize	0.0018	0.0009	0.0009	-0.0001	-0.0001
	(0.0013)	(0.0009)	(0.0012)	(0.0008)	(0.0013)
rev	0.0139***	0.0131***	0.0131***	0.0171***	0.0171***
	(0.0027)	(0.0023)	(0.0031)	(0.0026)	(0.0055)
donor	-0.0094***	-0.0090***	-0.0090**	-0.0128***	-0.0128**
	(0.0031)	(0.0027)	(0.0035)	(0.0028)	(0.0057)

Table 2 (continued)
Cost Equation Estimations

	(1) OLS	(2) RE	(3) RE_ROB	(4) FE	(5) FE_ROB
hosp	-0.0113***	-0.0102***	-0.0102***	-0.0138***	-0.0138**
	(0.0028)	(0.0023)	(0.0033)	(0.0027)	(0.0062)
other	-0.0119***	-0.0112***	-0.0112***	-0.0162***	-0.0162**
	(0.0027)	(0.0024)	(0.0033)	(0.0029)	(0.0065)
invest	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
d1989	0.0269	0.0414	0.0414	0.0620**	0.0620***
	(0.0407)	(0.0320)	(0.0353)	(0.0266)	(0.0225)
d1991	0.0032	0.0220	0.0220	0.0181	0.0181
	(0.0314)	(0.0337)	(0.0295)	(0.0288)	(0.0292)
d1999	-0.0910**	-0.0519	-0.0519	-0.0005	-0.0005
	(0.0413)	(0.0355)	(0.0382)	(0.0314)	(0.0379)
d2002	-0.0724	-0.0311	-0.0311	0.0147	0.0147
	(0.0469)	(0.0414)	(0.0443)	(0.0376)	(0.0489)
d2005	-0.1041**	-0.0370	-0.0370	0.0599	0.0599
	(0.0503)	(0.0438)	(0.0444)	(0.0401)	(0.0518)
d2008	-0.0774*	-0.0067	-0.0067	0.1003**	0.1003*
	(0.0431)	(0.0435)	(0.0416)	(0.0412)	(0.0580)
d2010	-0.0716	-0.0023	-0.0023	0.1146**	0.1146*
	(0.0473)	(0.0463)	(0.0460)	(0.0443)	(0.0656)
d2011	-0.0940**	-0.0146	-0.0146	0.1049**	0.1049
	(0.0454)	(0.0462)	(0.0446)	(0.0450)	(0.0675)
constant	9.3524***	9.4819***	9.4819***	10.1525***	10.1525***
	(0.1481)	(0.1068)	(0.1539)	(0.1027)	(0.2025)

Standard errors in parentheses; N = 506 for each estimation
* p<0.10, ** p<0.05, *** p<0.01

Table 3A
Total Cost Deconstruction
Loose Revenue Constraint: 1987 to 2008

	Estimate	Lower[a]	Upper[a]
Actual Change	$32,022		
Cost Saving	−$7,573	−$12,526	−$2,620
Program Changes	−$6,063	−$12,715	$590
Change	$45,658	$36,469	$54,848
Involuntary Cost Increases:			
Salaries	$3,741	$1,400	$6,083
Benefits	$837	−$1,570	$3,244
Subtotal	$4,578	$2,289	$6,868
Voluntary Cost Increases:			
Productivity	$12,376	$3,363	$21,389
Salaries	$2,293	$858	$3,728
Benefits	$513	−$962	$1,989
Governance	$535	−$794	$1,863
Revenue	$10,740	$5,992	$15,487
Subtotal	$26,457	$16,025	$36,889
Explained	$31,035	$19,046	$43,024
Voluntary/Involuntary Cost Ratio:	5.78		

[a] 95 % Confidence Bounds

Table 3B
Total Cost Deconstruction
Tight Revenue Constraint: 2008 to 2011

	Estimate	Lower[a]	Upper[a]
Actual Change	$4,680		
Cost Saving	−$3,829	−$7,196	−$461
Program Changes	−$2,081	−$3,761	−$402
Productivity	−$442	−$1,402	$518
Change	$11,032	$6,640	$15,425
Involuntary Cost Increases:			
Salaries	$1,063	$393	$1,733
Benefits	$306	−$587	$1,200
Subtotal	$1,369	$524	$2,215
Voluntary Cost Increases:			
Productivity	$442	−$518	$1,402
Salaries	$651	$241	$1,062
Benefits	$188	−$360	$735
Governance	$94	−$134	$322
Revenue	$6,430	$3,194	$9,667
Subtotal	$7,806	$4,104	$11,509
Explained	$9,176	$5,293	$13,058
Voluntary/Involuntary Cost Ratio:	5.38		

[a] 95 % Confidence Bounds

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Referee Appendix: The Partial Differentials

The log-linear specification in (1) implies the expectation

$$E\left(tc_{it}\right)=\exp\left(\beta' x_{it}+\alpha_i\right)E\left[\exp\left(u_{it}\right)\right]=\exp\left(\beta' x_{it}\right)\exp\left(\alpha_i\right)E\left[\exp\left(u_{it}\right)\right] \quad (2)$$

The predicted value should incorporate an estimate of $E\left[\exp\left(u_{it}\right)\right]$. We use the sample average of the fixed effects residuals $N^{-1}\sum_i\sum_t \exp\left(\hat{u}_{it}\right)$[19], where N = 506 is the total number of estimation sample observations. Other variants tried included the usual correction factor for the log-normal model $\exp\left(0.5\sigma^2\right)$, and also a group mean $\bar{\hat{u}}_{i\bullet}=T_i^{-1}\sum_t \exp\left(\hat{u}_{it}\right)$. Each of these corrections is very small and there were no meaningful differences among them in our calculations. Thus the predicted tc_{it} is

$$tc_{it}=\exp\left(\hat{\beta}' x_{it}\right)\exp\left(\hat{\alpha}_i\right)\left\{N^{-1}\sum_i\sum_t \exp\left(\hat{u}_{it}\right)\right\}$$

The total differential of $E\left(tc_{it}\right)$ is

$$dE\left(tc_{it}\right)=\exp\left(\beta' x_{it}\right)\exp\left(\alpha_i\right)E\left[\exp\left(u_{it}\right)\right]\left(\beta' dx_{it}\right)$$

We wish to compare outcomes in 1987 to those in 2008, and outcomes in 2008 to those in 2011. For each university *i*, we calculate

$$d(tc_i)=w_i\exp\left(\beta' x_{i,base}\right)\exp\left(\alpha_i\right)E\left[\exp\left(u_{it}\right)\right]\left(\beta' dx_i\right)$$

where $x_{i,base}$ are regressor values in the base year 1987 or 2008, and $dx_i=x_{i,2011}-x_{i,2008}$ or $dx_i=x_{i,2008}-x_{i,1987}$.[20] The differential is weighted by base year FTE student enrollment. Define

[19] Cameron and Trivedi (2010, 108) .

[20] While our panel is unbalanced we have 55 matching observations for 1987, 2008 and 2011. We use these observations to compute the comparison values.

$$w_i = ftestu_{i,base} \Big/ \left(\sum_{i=1}^{n} ftestu_{i,base} \right)$$

Then

$$d(tc) = \sum_{i=1}^{n} w_i \exp\left(\beta' x_{i,base}\right) \exp\left(\alpha_i\right) E\left[\exp\left(u_{it}\right)\right]\left(\beta' dx_i\right)$$

$$= \sum_{i=1}^{n} c_i \exp\left(\beta' x_{i,base}\right)\left(\beta' dx_i\right)$$

where $c_i = w_i \exp\left(\alpha_i\right) E\left[\exp\left(u_{it}\right)\right]$. The estimator of *d*(*tc*) is

$$d(tc) = \sum_{i=1}^{n} \hat{c}_i \exp\left(\hat{\beta}' x_{i,base}\right)\left(\hat{\beta}' dx_i\right) \tag{2}$$

Where $\hat{\beta}$ is the fixed effects estimator, and $\hat{c}_i = w_i \exp\left(\hat{\alpha}_i\right)\left\{N^{-1} \sum_i \sum_t \exp\left(\hat{u}_{it}\right)\right\}$. Since is a nonlinear function of the estimator $\hat{\beta}$ inference uses the delta method[21]. The asymptotic distribution of the estimator in (2) is

$$g\left(\hat{\beta}\right) \overset{a}{\sim} N\left[g\left(\beta\right), JVJ'\right]$$

where $J = \partial g\left(\beta\right) / \partial \beta'$, so that the estimator of the asymptotic variance of $d(tc)$ is $\hat{V}_{d(tc)} = \hat{J}\hat{V}\hat{J}'$, with $\hat{J} = \partial g\left(\beta\right) / \partial \beta' \big|_{\beta = \hat{\beta}}$ and $\hat{V}$ is a robust cluster corrected covariance matrix of $\hat{\beta}$.[22]

Given the form of the differential in (2) the Jacobian is

$$J = \sum_{i=1}^{n} c_i \left[\exp\left(\beta' x_{i,base}\right)\left(\beta' dx_i\right) x'_{i,base} + \exp\left(\beta' x_{i,base}\right) dx'_i\right]$$

$$= \sum_{i=1}^{n} c_i \exp\left(\beta' x_{i,base}\right)\left[\left(\beta' dx_i\right) x'_{i,base} + dx'_i\right]$$

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[21] William Greene (2012, Theorem D.22, 1086).

[22] Coefficient estimation was carried out using Stata 12.1. Subsequent calculations were carried out in SAS 9.3/IML.