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ABSTRACT

The Information Exchange Procedures (IEP), which were developed through a project sponsored by the National Center for Higher Education Management Systems, are briefly described, and the application of the IEP in Virginia is examined. The IEP were designed to enhance the institution's ability to identify alternatives in the allocation of resources and related management functions. The procedures for IEP consist of merging three categories of data: course enrollments, faculty activities, and financial expenditures. In the mid-1970s Virginia adopted the IEP costing procedures (with some modifications) to provide information on modified direct cost. A study was conducted to evaluate the stability and consistency of IEP unit costs and productivity ratios for two major research universities for 1978-1979 and 1980-1981. It was assumed that figures for comparable activities at similar universities would have consistency and similarity over time. Two indices were obtained: direct cost per student credit hour and student credit hours generated per full-time equivalent faculty position. The assumption of comparability was found to be less valid than stability over time, since errors over institutions were larger than errors over time. This finding casts doubt on the reliability of comparing IEP indices across research universities. (SW)

EVALUATING THE RELIABILITY OF INDICES FROM IEP

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D. R. Coleman, Chairman
Forum Publication
Advisory Committee

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Evaluating the Reliability of Indices From IEP

When the computer age came to higher education in the 1950's and the 1960's, administrators discovered that they could monitor major parts of the educational process. While some of this monitoring was brought about by the need to demonstrate our openness to those of various races and economic backgrounds, much of the force came from our curiosity and our predisposition to centralize administrative processes; moreover, computers made monitoring possible. In the ensuing timeframe, various "models" became available: RRPM, CAMPUS, etc., (Bleau, 1981; Hopkins and Massey, 1981). Meanwhile, a decline in financial resources and fewer high school graduates made life more difficult at some institutions. The inclination to monitor at the institutional and state level gave way to more centralized management. But the tools to undertake such management had received limited testing.

History of IEP

During the early seventies the National Center for Higher Education Management Systems (NCHEMS), with assistance from a task force and a steering committee composed of institutional and state agency representatives, initiated a project called the Information Exchange Procedures (IEP). The initial procedures, intended to isolate component costs of an institution's operation, were tested in 1972-73 in about twenty community colleges, twenty private colleges, and twenty state colleges and universities. The results of this test were used to refine the procedures which were tested again 1973-74 in approximately the same number of institutions. After further refinements, institutions and state agencies across the states adopted the procedures to collect and to develop cost data.

Purpose and Assumptions of IEP

The general goal of the information exchange according to NCHEMS (1976) was to improve planning and management in postsecondary education and

> To support institutional identification, acquisition, and use of information necessary to carry out institutional comparative analysis, particularly in the area of resource allocation. [Resource allocation refers to the identification of alternatives and selection of the most feasible for distributing resources (personnel, monies, facilities, and so forth) among the institution's competing programmatic activities.]

The underlying principle for this objective was to enhance the institution's ability to identify alternatives in the allocation of resources and related management functions. Basic assumptions supporting the IEP costing procedures were: (1) the availability of better information would lead to improved institutional planning and management; (2) comparative analyses (relative to other institutions) would provide useful bases for the formulation of alternatives in planning and management decisions; and (3) compatible data could be achieved across institutions by establishing a fixed structure and data definitions. Other original assumptions were: (1) the same set of historical measures could be used to portray any educational institution; and (2) institutions could implement IEP with relative ease and minimal cost.

It soon developed that a difference existed between theory, grand phrases, and practical applications. Complex research universities that used IEP costing procedures quickly discovered that the procedures were both inappropriate and costly. In particular, the non-compatibility of data (at least from the viewpoint of some institutions) has precluded any serious comparative analyses of data among or between institutions. But it no longer mattered. State agencies had a black box solution to information processing that had been blessed by NCHEMS. Even though NCHEMS later sought to mollify the complex universities by publishing statements that for major research universities there was particular cause for concern about the validity and comparability of cost and productivity ratios produced by the IEP software (1975, 1977), it was too little and too late. IEP had come to stay, except where its costs and complexity so strangled the entire system that it had to be dropped (as in Colorado).

Description of IEP

The procedures for IEP consist of merging three categories of data: (1) data describing course enrollments; (2) data describing the activities of the faculty, and (3) financial expenditure data.

The most detailed part of IEP consists of procedures to prepare cost data. In general, the cost study procedures describe the total annual expenses of institutional activities, as well as average discipline and programmatic costs in instructional areas. In theory, such information compiled from IEP cost reports could assist an institution to formulate alternative plans, allocate resources, evaluate programs, and manage resources.

The cost procedures' portion of IEP is implemented through a set of NCHEMS designed computer software. The software is comprised of four modules: a Student Data Module (SDM), a Personnel Data Module (PDM), an

Account Crossover Module (ACM), and a Data Management Module (DMM). SDM processes student registration information into an instructional matrix to reflect the interaction of departmental instruction and course taking by majors. PDM processes personnel information to calculate crossover instructions by allocating personnel and their funding to the tasks they perform. ACM processes the accounting information of the institution. Information from the institution's accounting systems is converted to IEP activity or classification structures. DMM acts as a storage and manipulation mechanism for information obtained from the other modules. As can be seen this is a comprehensive data base. As implemented in Virginia, the information on faculty effort is obtained from instructional assignments rather than a faculty activity survey.

Table 1 about Here

Commonwealth of Virginia Experience

In the mid-seventies, the State Council of Higher Education for Virginia (SCHEV) adopted the NCHEMS IEP costing procedures with some modifications. Essentially, the modifications included changing the program classification structure to match Virginia's, adding a source of funds designation, and adapting a standard nomenclature for parameter identifiers. The intent was to provide information on modified direct cost. Thus, since 1975-76 state institutions in Virginia have been required to prepare and submit to SCHEV various reports generated by the NCHEMS software.

The reasons given by SCHEV for adopting the NCHEMS IEP costing procedures were as follows:

1. It would provide information previously not obtainable from most institutions.

2. It would reduce the number of reports to be submitted to SCHEV annually.

3. It would eliminate cumbersome and artifically structured reports.

4. It would provide standard procedures and mechanisms for analysis of data by both institutions and SCHEV. (SCHEV, 1980)

In all of the purposes noted above, it is obvious that the underlying assumption is made that reasonably consistent and stable cost and productivity ratios can be computed. There are in fact several reasons that the software may not produce such numbers. The most obvious reason for inconsistency in the numbers comes from the fact that no institution ever has an error free data base. The second and more complex problem is that it may not be possible to trace resources from one source into numerous subactivities (Thomas, 1977). This need to perform forked allocations is central to the software used in Virginia.[1] It attempts to replicate reality by the allocation of faculty activity based on course credit hours by course level while Thomas notes (1982) "any attempts to allocate costs to interacting faculty activities are inevitably productive of nonsense."

A discouraging look at the hopes of obtaining concise information on appropriate ways to split faculty salaries into pieces representing faculty effort on various courses and instructional activities can be obtained by comparing the conclusions of Stecklein (1961) with those of Yuker (1974). Stecklein (1961) concludes that "much additional probing is needed into differences in the amounts of time needed to teach courses at the different levels . . ." while Yuker concludes: "The number of articles devoted to faculty workload testifies to the continuing interest in the topic. Despite this interest there have been comparatively few advances since the pioneering study by Koos in 1919." It is interesting that Yuker discounted the use of faculty course credit hours as a valid measure of how faculty time was spent. This is the measure used in Virginia to allocate a faculty member's salary into various levels of instruction when the faculty teaches at more than one course level.

Based on the warnings of such writers as those mentioned above, the procedures used in IEP were open to questions of validity. While establishing validity is complex, it must start with the investigation of the reliability of the resulting measures. The absence of rigorous evaluations of the stability and consistency of measures produced by these systems is particularly disturbing given the assumptions used in IEP and the reasons given for its use.

The purpose of this research is to evaluate the stability and consistency of unit costs and productivity ratios for two major research universities. Since IEP purports to provide reliable comparative information, it might reasonably be expected that figures for comparable activities at two similar universities should have consistency and similarity over time.

The source of the data used in this research was the IEP data provided to the State of Virginia by two comprehensive research universities for the 1978-79 and the 1980-81 periods. Two indices were obtained; direct cost per student credit hour (Cost Ratio or CR) and student credit hours generated per full-time equivalent faculty position (Productivity Ratio or

PR). These ratios were obtained for each course level (lower and upper undergraduate and first and advanced graduate) for each Higher Education General Information Survey (HEGIS) number reported as representing a curriculum offering; we call each cell (datum) a cost center.

There were a total of 358 cost centers in both institutions for the two points of time. Of these, 294 were replicated over time in at least one institution but only 84 were replicated over institutions at least one point of time.[2]

We investigated two concepts. First, that it was possible to use information from a cost center at one university to anticipate the characteristics of a cost center at the other university. In this analysis we assumed that the estimate used would be the average of existing information. The error is the variance of the available indices about the mean index over the cost centers that occurred at least once in both institutions.[3] These results compare the two institutions at both points in time. If there exists some intrinsically correct index for the cost center, then a coefficient of "consistency" can represent the reliability of the measure for a given point of time. For example, given a cost center which might be measured at points 1-4:

	Institution 1	Institution 2
Time 1	1	2
Time 2	3	4

then consistency requires that the index in 1 and 2 are comparable and the indices in 3 and 4 are comparable. Furthermore, if it is assumed that time effects are randomly equivalent, then the combined information where each cost center is measured in cell 1 and 2 and/or 3 and 4 is also a measure of consistency. Lack of consistency is the difference of any observation from the mean of the observation for the cost center.

If an index is stable at institution 1, it will have the same value in cell 1 as in cell 3. The same applies to institution 2. To find the combined index of stability when data were available in all four cells, the average of the four cells was used as the estimate of the "true" index; variations from it were considered to represent instability.

The definition of error in both of the preceeding assessments is obviously a characteristic of the use of indices from IEP and includes more than simply the mechanical errors in the data preparation or manipulation for the preparation of IEP. It also includes the fact that there are actual shifts in processes over time and "true" difference between institutions. As a consequence it is possible to identify errors of inconsistency or errors of instability in the data; the possibility of the existence of such problems does not exist in the user manuals.

The statistical analyses used herein were obtained from PROC VARCOMP of SAS using the procedure recommended by Winer (1962). This procedure assumes that the measures are parallel and that differences in means are attributable to error. Analogous to the intraclass correlation, differences in cell means are included as error variance giving a somewhat lower but more appropriate estimate of reliability.[4]

Results

Table 2 shows the reliabilities and Standard Errors of Measurement (SEM) for the two indices of stability and consistency.

Table 2 about here

Uncertainty Theory: An Alternative

The analysis above is based on the traditional model of normally distributed errors uncorrelated with true scores. The unexplained variations in the ratios of the IEP indices are not independent of the indices, and furthermore, the indices are negatively skewed, being bunched at the low end and with an extremely long tail to the higher numbers. In the face of these characteristics, it seemed necessary to investigate alternatives to the traditional approach. The alternative that follows is based on the entirely different approach of determining the amount of certainty that can be given to the numbers that result from functions based on fallible data.

When errors are presumed to have occurred in the data and in the subsequent manipulation of these data, uncertainty exists about the accuracy of the resulting measures. By uncertainty we mean that the quantitative measure may, or may not, describe accurately the actual performance of the institution. The reliability of the report then must be determined by an understanding of the behavior of the measures with respect to errors in both the primary data and in the subsequent analyses of these data.

In addressing an analogous problem in the design and conduct of engineering experiments, Kline and McClintock (1953) show that an estimate of the uncertainty in a single or limited sample experiment may be quantified prior to the experiment using the following equation.

$$W(R) = \sqrt{\sum_{n} \left(\frac{\partial R}{\partial x_i} W x_i\right)^2}$$

where: R = $f(x_1, x_2, x_3, \ldots, x_n)$

x = n independent variable

Wx_i = the experimenter's estimate of the uncertainty in the measurement of x_i and

W(R) = the resulting uncertainty in the accuracy of R.

This can be nondimensionalized by dividing both sides by R. The nondimensional form is important since it frequently simplifies the mathematical expression, and produces a value for uncertainty that is independent of the magnitude of R. Kline and McClintock have shown that if p represents the probability that the true value of each of the x falls within ± W(x) then p also denotes the probability that R falls within R ± W(R).

Two aspects of their analysis appear of particular interest to institutional researchers. First, R is not assumed to be uniformly sensitive to the change introduced by errors in each of the independent variables. Since the implications of change in the accuracy of the primary data, or the modification of the report can be assessed, the analysis of uncertainty provides a basis for improving the usefulness of management reports.

The second important aspect of their analysis deals with estimating the subjective probability of x falling with ± W(x). Neither the experimenter nor the institutional researcher has a precise means of determining the actual occurrence of errors in a single sample experiment, or a single report preparation cycle. In effect, the equation above provides an estimate of the experimenter's confidence in the results that would be rigorously determined as a confidence limit if the power of statistics could be brought to bear on a significant number of observations. Lacking concrete means to determine the error, Kline and McClintock argue that these estimates are preferable to the assumption that no error occurred.

Application of Uncertainty Analysis to IEP Productivity Ratios

To examine the uncertainty inherent in the determination of a quantitative measure reported in IEP, consider the productivity ratio (PR) for a cost center as given by

$$PR = S/F$$

where: S denotes the student credit hours taught in the cost center and

F denotes the full-time-equivalent faculty traced to the cost center.

While sufficient information is not available to evaluate fully the appropriateness of Kline and McClintock's procedure for the IEP data used in this study, the following will investigate the outcomes when their procedure is applied to three different models of the IEP data. Each model is developed and evaluated both for additive and multiplicative error terms. The derivation of the resulting uncertainty, both for the additive and the multiplicative models, are shown in the Appendix.

Indices Model:

The simplest model is one to show that the indices (I) are operating under a general additive framework, W(I) = a. [This assumption results in uncertainty that is a constant over the range of measures.] The relationships shown in Figure 1 and 2 show clearly that the average uncertainty, measured as the average absolute difference between estimates of the cost and productivity ratios, is an increasing function of the magnitude of the index.[5] The assumption of additive uncertainty can not be accepted.

A second alternative in such a model is to assume that the uncertainty on the index (I) is a multiplicative function (A) of the index: that W(I) = A*I. This approach suggests that the lines shown in Figures 1 and 2 could be expected, and it implies that in general there is no relationship between uncertainty and the size of the department. The results shown in Figures 3 and 4 partially support this model in that they are relatively linear for departments with more than ten faculty. The model, however, does not appear acceptable when dealing with small departments.

Ratio Model:

The next level of sophistication of the use of Kline and McClintock's procedure is to assume that the numerator and the denominator of the indices have uncertainty. In this second model the assumptions made for the separate pieces of the additive model do not fit the results from the data as shown in Figures 5 through 7. It is apparent that discrepancies in the components of the ratios are directly related to the magnitude of these components: The multiplicative model results in a constant uncertainty for the space of the numerator and denominator. This was not the case as shown in Figures 8 and 9.

Component Model:

The third level of sophistication in modeling for uncertainty is to assume that the numerator and the denominator of the indices are composed of the sum of fallible data elements. The results of uncertainty in the additive and multiplicative models indicate that as the size of the department increases, uncertainty of the ratio decreases. In fact, the results are differentiated by their dependence on the size of the pieces of SCH and FTE; therefore, we can not generate hypotheses about the curves to determine their relative appropriateness with the existing data base. It is possible to take the results of both and try the equation

$$\frac{Wpr}{PR} = \sqrt{\left(\frac{a}{S}\right)^2 + \left(\frac{b}{F}\right)^2}$$

Figure 10 shows the results of this equation when the data are fitted to Time 1 and Time 2 information and: a = 2.23, b = .032. The results shown in Figure 10 support both hypotheses since the uncertainty in the nondimensionalized form does in fact decrease when the size of the department increases.

Figures 1 through 10 about here

In the absence of an assumption about perfect data and perfect processing of these data, a rational decision-maker should question the reliability of productivity ratios having small numbers of faculty members, or small fractions, of FTE associated with each faculty member's teaching efforts.

Since the larger the cost center, the more reliable the figure, the distribution of values for both F (faculty) and S (students) offer an interesting insight into the design of the IEP reporting process. Figure 11 depicts the distribution of the values of F for all reported cost centers in the Virginia IEP (VaIEP) reports that were submitted by the senior institution in Virginia to the State Council of Higher Education for Virginia (SCHEV); Figure 11 provides the distribution of S for the same institutions.

Insert Figures 11 and 12 here

From Figure 10, it is clear that uncertainty increases dramatically for productivity ratios calculated on the basis of less than one FTE faculty, regardless of assumptions about the magnitude of the error terms. From Figures 11 and 12, it is clear that over 60% of the productivity ratios reported in VaIEP are based upon calculations performed on these very small cost centers. Since the uncertainty inherent in the ratios calculated for these small cost centers is large, the reliability of these measures for cost centers is nil. For example, if we use the weights developed for Figure 10 and the actual State IEP data distribution for the 10th percentile; S = 19 and F = .09; then Wpr/PR = .35. In other words, for cost centers this size, the expected absolute average difference in PR over time would be about 1/3 PR. At the 20th percentile, the comparable data are S = 40, F = .17, and Wpr/PR = .19. The range of uncertainty as shown herein displays the fact that 1 out of 5 cost centers will have at least this amount of instability--given our definitions. Another way to consider these results is to note that cost centers with fewer than .01 FTE Faculty will have a minimum uncertainty of about 3 times the size of the index regardless of the number of credit hours.

Discussion

While man-machine information systems represent increasingly accurate means of maintaining and manipulating large amounts of data, these systems do not function perfectly. When error is assumed to occur in the primary data and in the subsequent processing of these data, or to occur when assumptions were erroneous, uncertainty exists about the subsequent accuracy of derived measures describing institutional performance. The existence of error helps to explain the lack of stability of these measures over time and the lack of comparability in these measures across institutions. It does seem that there is more stability than consistency.

As observed in the estimate of consistency and stability with a traditional procedure, the standard errors indicate that while reliabilities seem adequate, the ratios have standard errors of about plus or minus $100 per credit hour and 200 credit hours per faculty. These standard errors are almost as large as the state medians for the cost ratios ($110 per credit hour) and the production ratio (240 credit hours per faculty member).

The section of the paper on uncertainty presents applications of a mathematical model to quantify estimates of the uncertainty due to error. Again, the indices seem to have more stability than comparability. Based on predictions from various applications of uncertainty models to empirical data, it is apparent that estimates from cost centers with fewer than .1 FTE faculty should be viewed with skepticism. As previously noted, the disaggregated data are required to determine the most appropriate assumption for the anticipated error in the component model. In addition, it is important to develop an uncertainty model reflecting the fact that the independent variables are related to each other.

When institutional data and the subsequent analyses of these data are presumed to be error free, a presumption of certainty typically exists. Users of the results tend to assume that quantitative measure describes actual institutional performance with <u>absolute</u> accuracy. The assumption of absolute accuracy is based on the presumption that large scale man-machine information systems function perfectly. In reality, however, errors of commission and omission occur in most, if not all, large scale data bases and reporting processes. These errors may be compounded by the untimeliness of the data, or the a posteriori nature of the demands made upon management information systems. Reporting efforts such as the IEP frequently require the coordination of data from multiple information systems. While each of these information systems may be adequate to meet the management needs it was designed to support, the lack of perfect coordination among these systems introduces additional error. The scale of reporting efforts effectively precludes human verification of the accuracy of all of the data. The manual verification of the data used in the preparation of one IEP report for a major research university would require person-years of effort. Given the frequency of error in manual verification, it is unlikely that human verification would detect or correct all of the data errors without introducing new errors in the review process. Even if one were to obtain mechanically perfect data, the indices of IEP would show instability and inconsistency because of the inappropriateness of the surrogate measures. It is obvious that the cautions of NCHEMS (1977) must be heeded.

Summary

The results of this study indicate that we should aggregate our existing data bases and resist the temptation to report at a level of detail where low stability and lack of consistency prevent any possible validity to the results. We found the assumption of comparability less valid than stability over time, for errors over institutions were larger than errors over time. This finding should be particularly disturbing to those who compare IEP indices across research universities.

TABLE 1

Data Elements for Virginia IEP

Data Element	Time Period
Student Registration Data	Fiscal Year
Student Identifier	
Course Data	
discipline	
course level	
credit hours	
Student Program	
Student Level	
Personnel Data	Fiscal Year
Faculty Identifier	
Faculty Name	
Faculty FTE	
Faculty Compensation	
Faculty Assignments	
instruction	
research	
administration	
etc.	
Financial Data	Fiscal Year
Year-End Expenditure Balances	
Adjustment/Crossover Instructions	

Table 2

Statistics for Consistency and Stability for Two IEP Indices

Stability

	Observations[a]		Cost Ratio r	SD	SEM[b]	Productivity Ratio r	SD	SEM
INST 1	(195)	390	.89(.80)	223.1	98.77	.93(.87)	431.6	155.1
INST 2	(168)	336	.87(.78)	140.1	66.35	.84(.73)	430.1	223.5
INST COMB	(294)	726	.88(.75)	190.8	95.52	.90(.78)	430.7	201.6

Consistency

	Observations		Cost Ratio r	SD	SEM	Productivity Ratio r	SD	SEM
TIME 1	(72)	144	.66(.48)	190.5	135.1	.69(.53)	423.4	289.9
TIME 2	(81)	162	.71(.56)	188.6	125.7	.88(.79)	329.7	151.3
TIME COMB	(84)	306	.87(.65)	189.4	111.5	.88(.67)	376.2	216.3

[a]An observation was not included unless it was represented either at both institutions at a given point in time (consistency) or at both times for a given institution (stability). The numbers in () represent unique cost centers. The others represent unique observations.

[b]The reliability in () and standard error of measurement are statistics expected if one were to use a single observation.

Figure 1

ABSOLUTE DIFFERENCE VERSUS AVERAGE VALUE FOR COST PER STUDENT CREDIT HOUR

Model: Y = a + bX. Corrs: r_s = 0.76, r_t = 0.64.

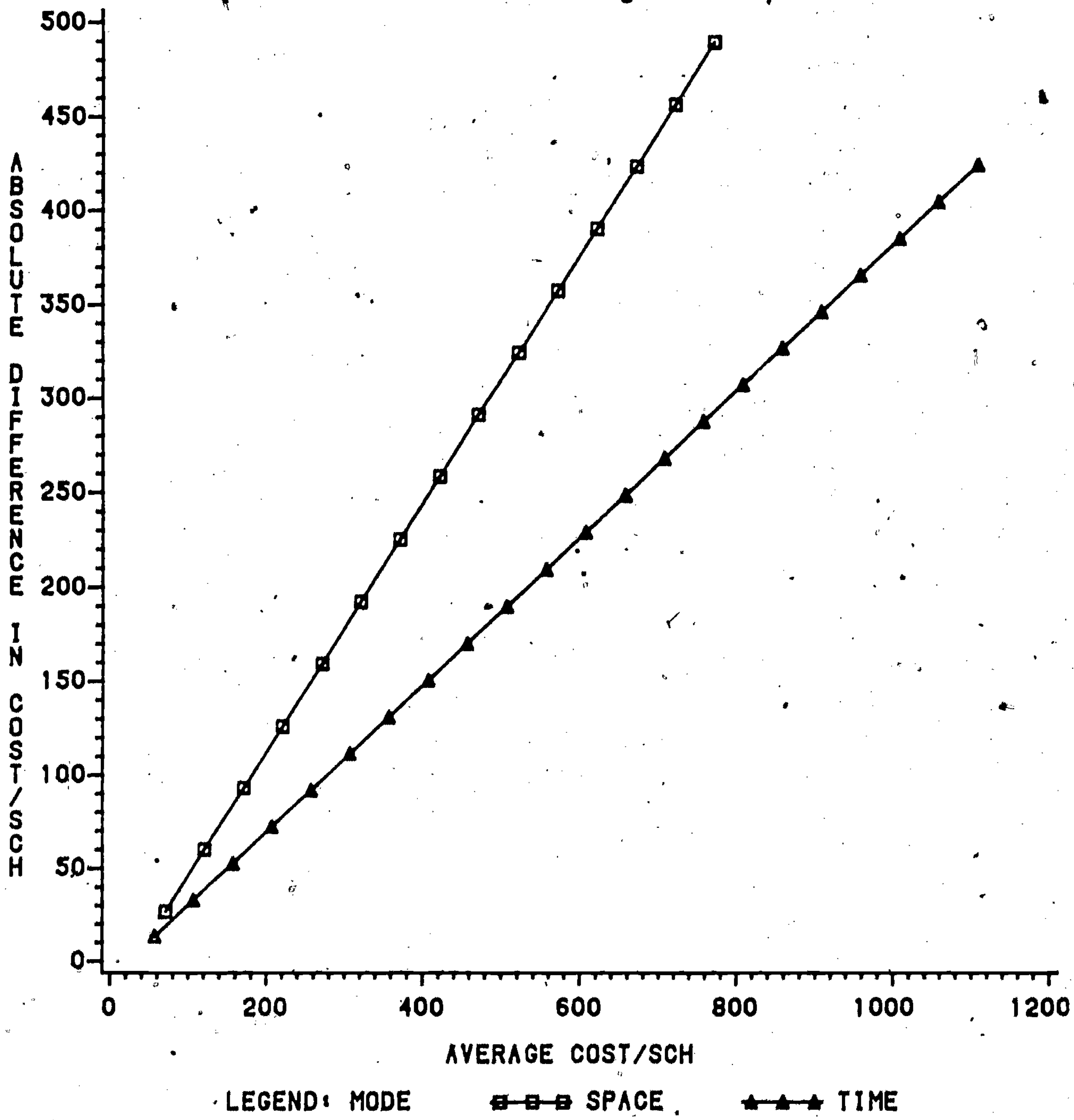


Figure 2

ABSOLUTE DIFFERENCE VERSUS AVERAGE VALUE FOR STUDENT CREDIT HOURS PER FTE FACULTY

Model: Y = a + bX. Corrs: r_s = 0.65, r_t = 0.71.

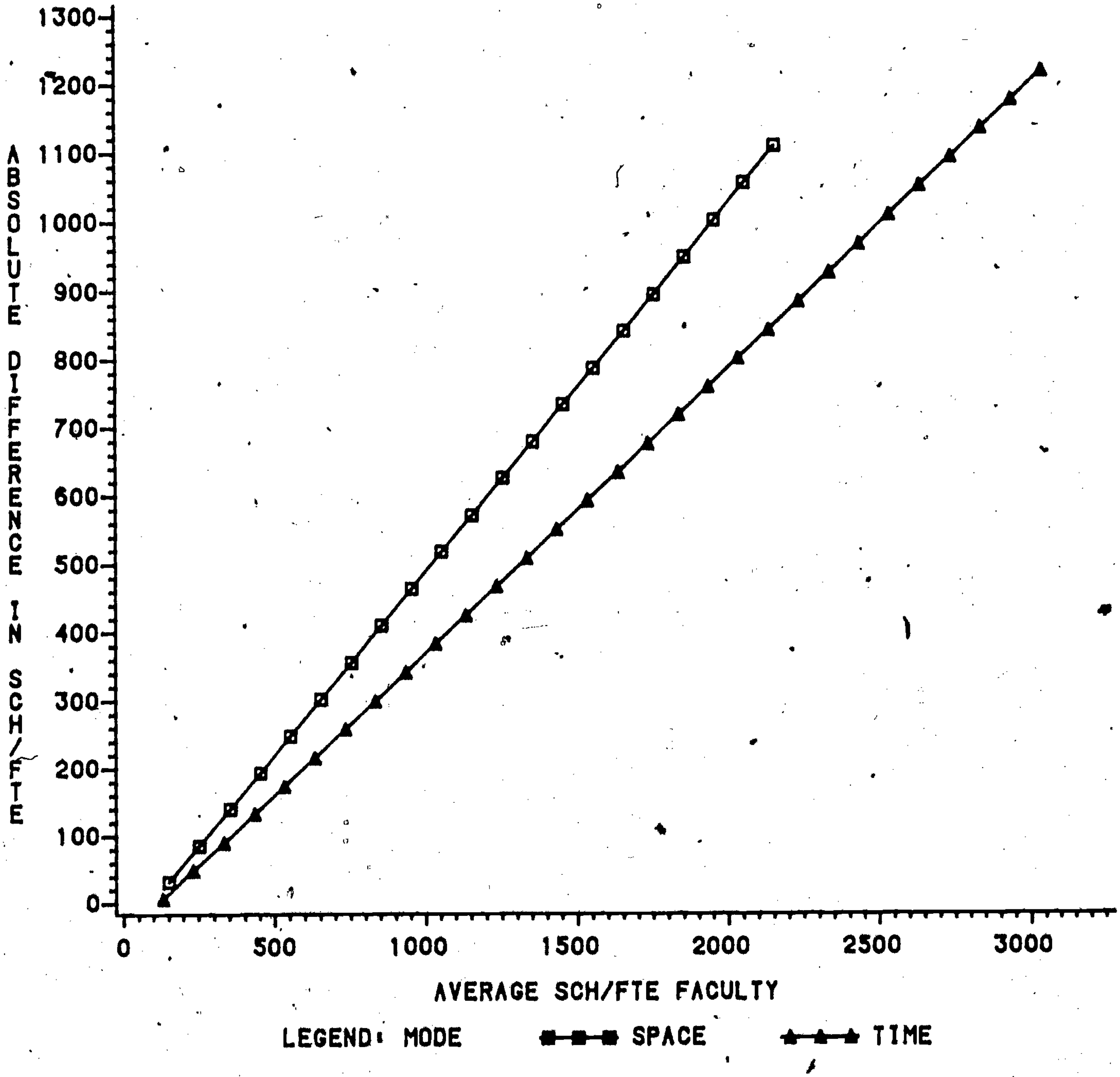


Figure 3

ABSOLUTE DIFFERENCE IN COST PER STUDENT CREDIT HOUR VERSUS AVERAGE FTE FACULTY

Model: $Y = bX^c$. Corrs: $r_s = 0.35$, $r_t = 0.22$.

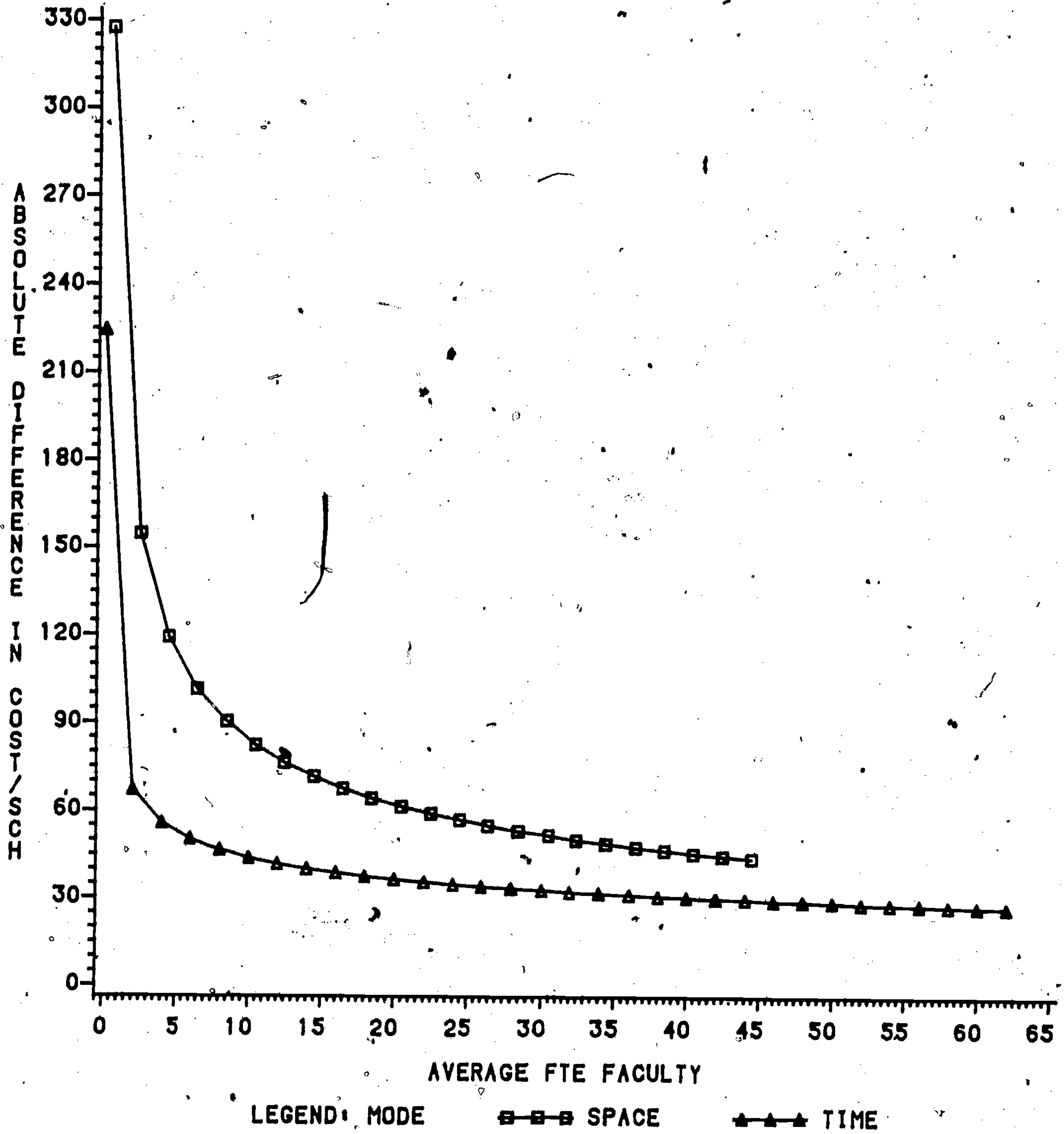


Figure 4

ABSOLUTE DIFFERENCE IN STUDENT CREDIT HOURS PER FTE FACULTY VERSUS AVERAGE FTE FACULTY

Model: $Y = bX^c$. **Corrs:** $r_s = 0.20$, $r_t = 0.26$.

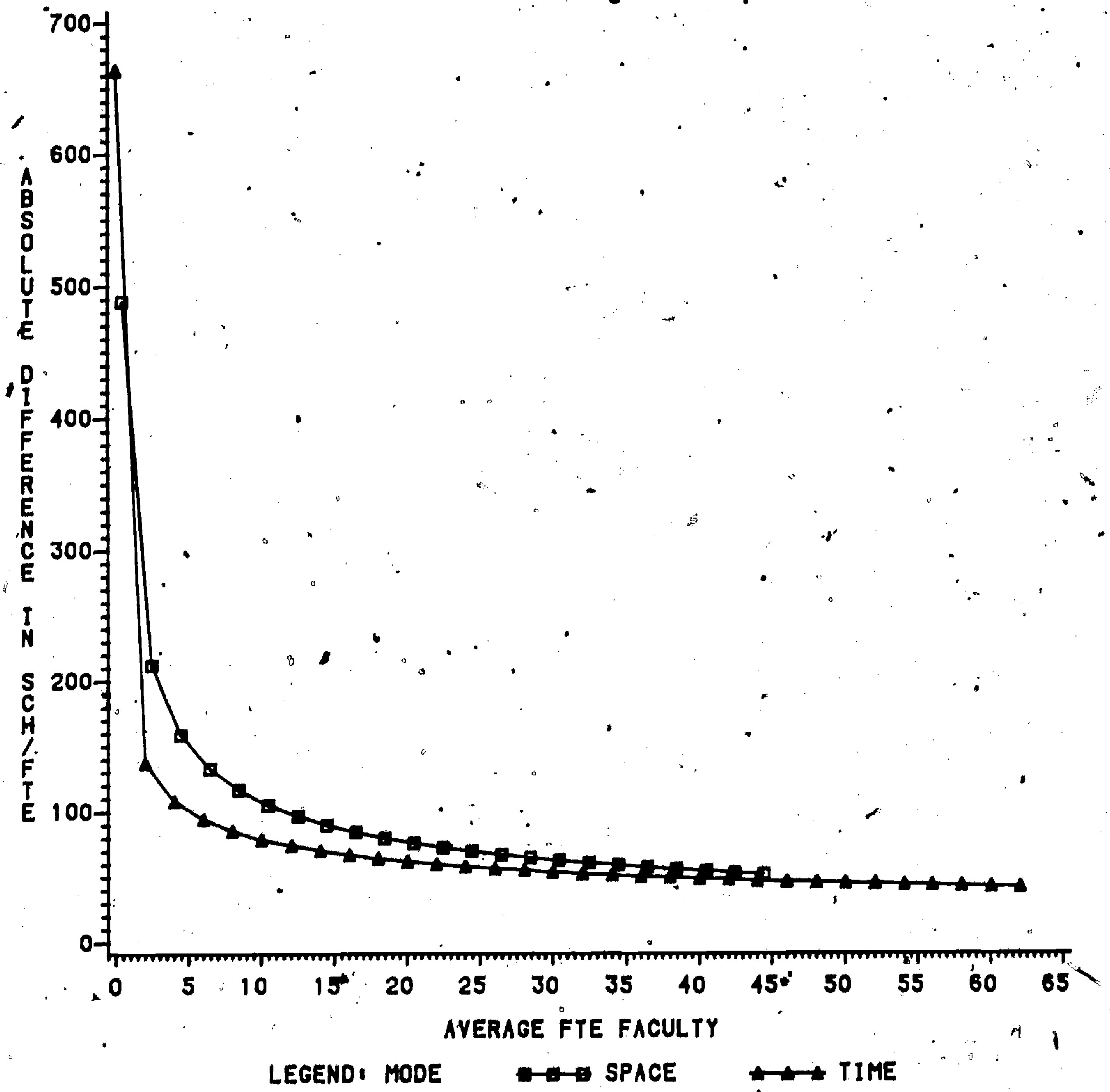


Figure 5

ABSOLUTE DIFFERENCE IN DIRECT COST VERSUS AVERAGE DIRECT COST

Model: $Y = a + bX + cX^2$. Corrs: $r_s = 0.68$, $r_t = 0.46$.

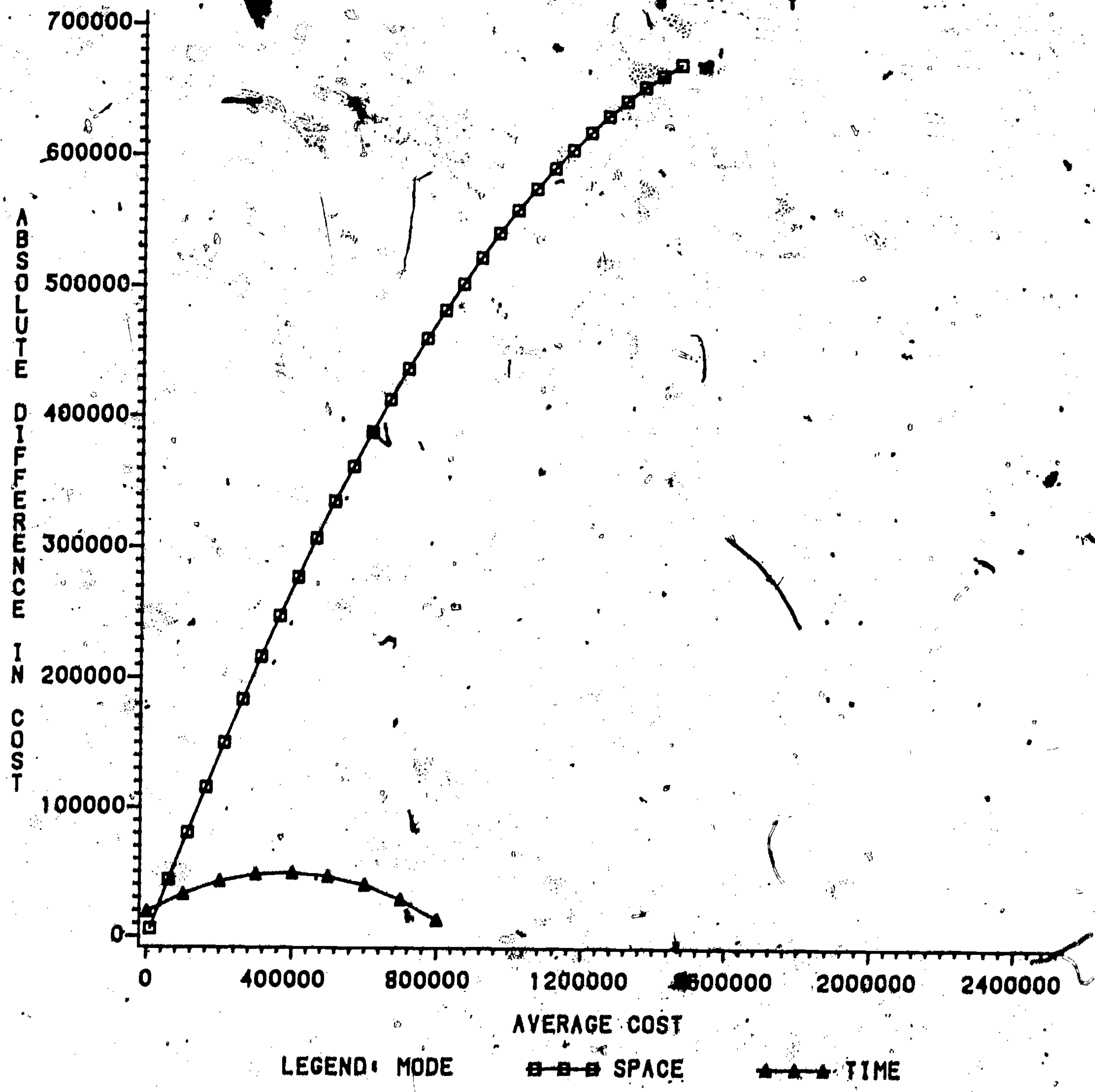


Figure 6

ABSOLUTE DIFFERENCE IN FTE FACULTY VERSUS AVERAGE FTE FACULTY

Model: $Y = a + bX + cX^2$. **Corrs:** $r_s = 0.80$, $r_t = 0.54$.

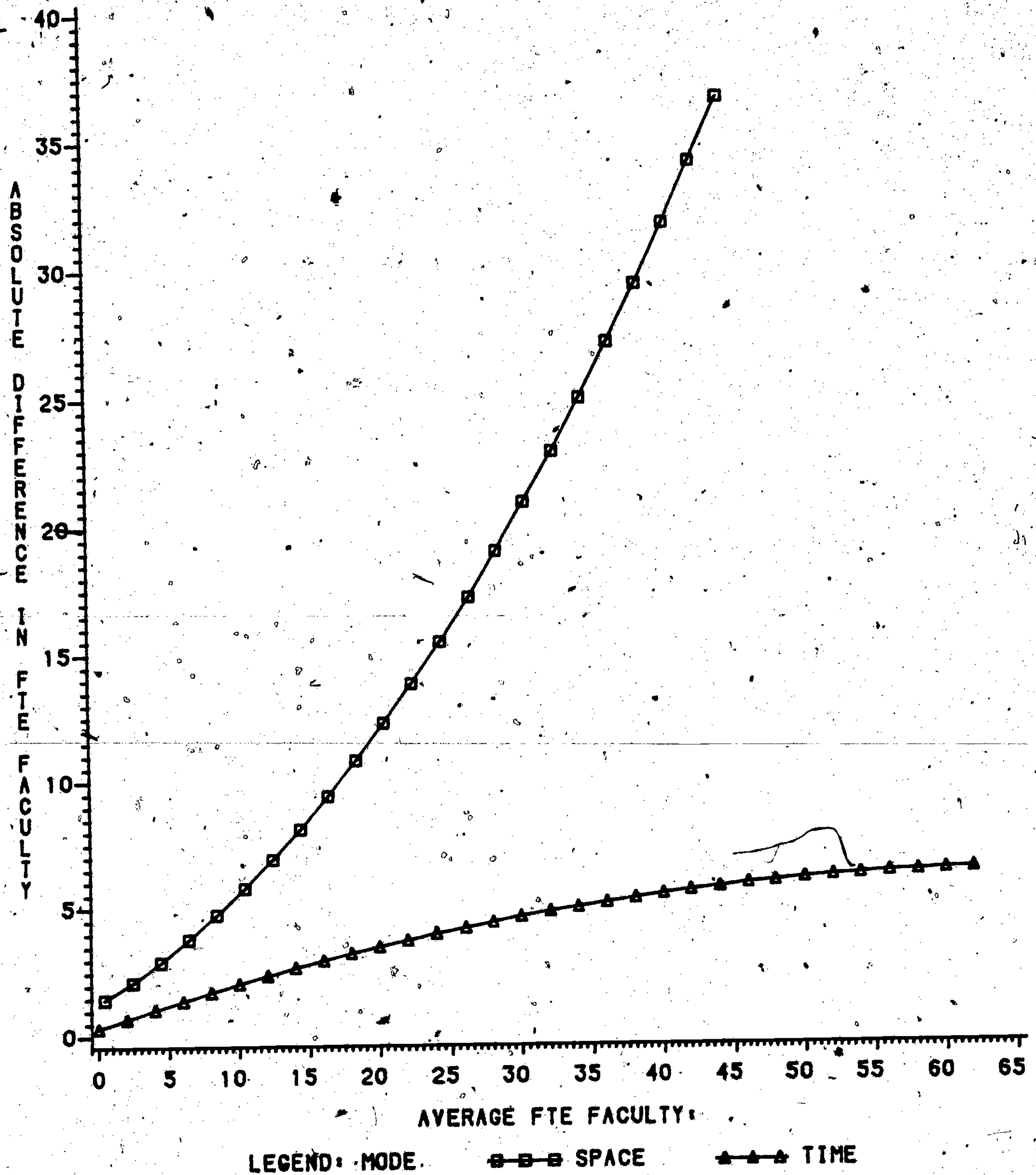


Figure 7

ABSOLUTE DIFFERENCE IN STUDENT CREDIT HOURS VERSUS AVERAGE STUDENT CREDIT HOURS

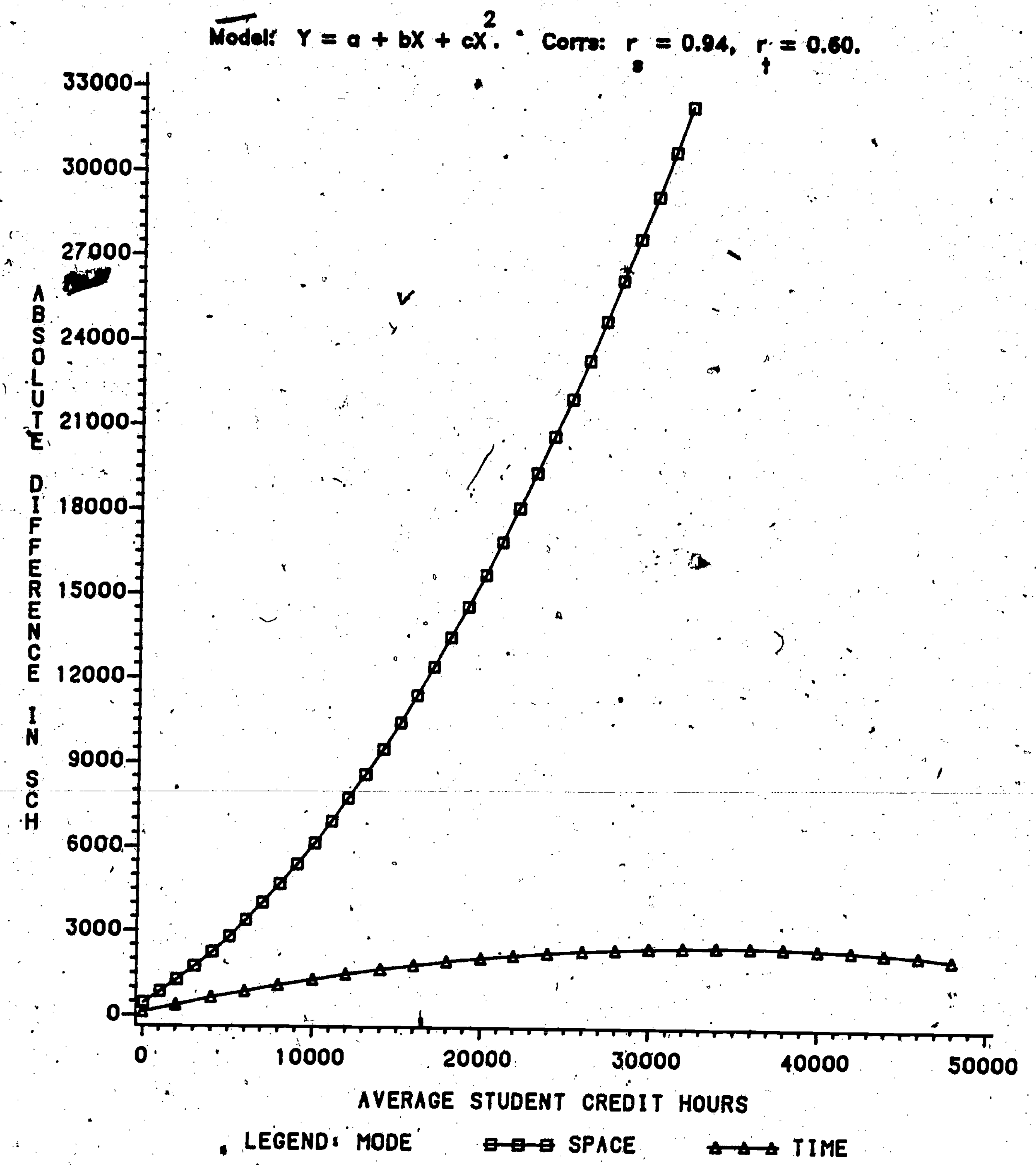


Figure 8

RELATIVE ABSOLUTE DIFFERENCE IN COST PER STUDENT CREDIT HOUR VERSUS AVERAGE FTE FACULTY

MODEL: $Y = bX^c$. Corrs: $r_s = 0.32$, $r_t = 0.33$.

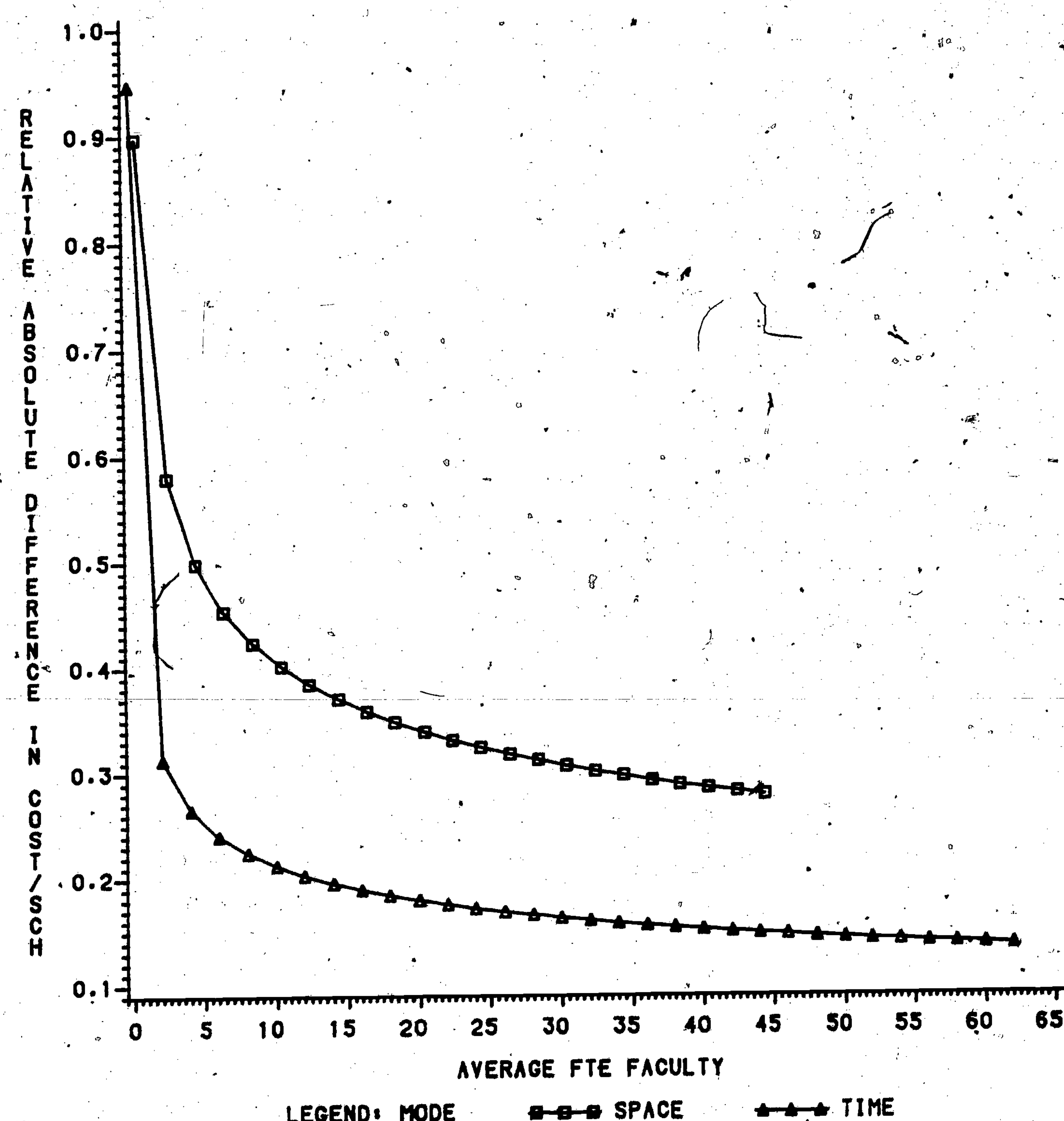


Figure 9

RELATIVE ABSOLUTE DIFFERENCE IN STUDENT CREDIT HOURS PER FTE FACULTY VERSUS AVERAGE FTE FACULTY

Model: $Y = bX^c$. *Corrs: $r_s = 0.39$, $r_t = 0.37$.

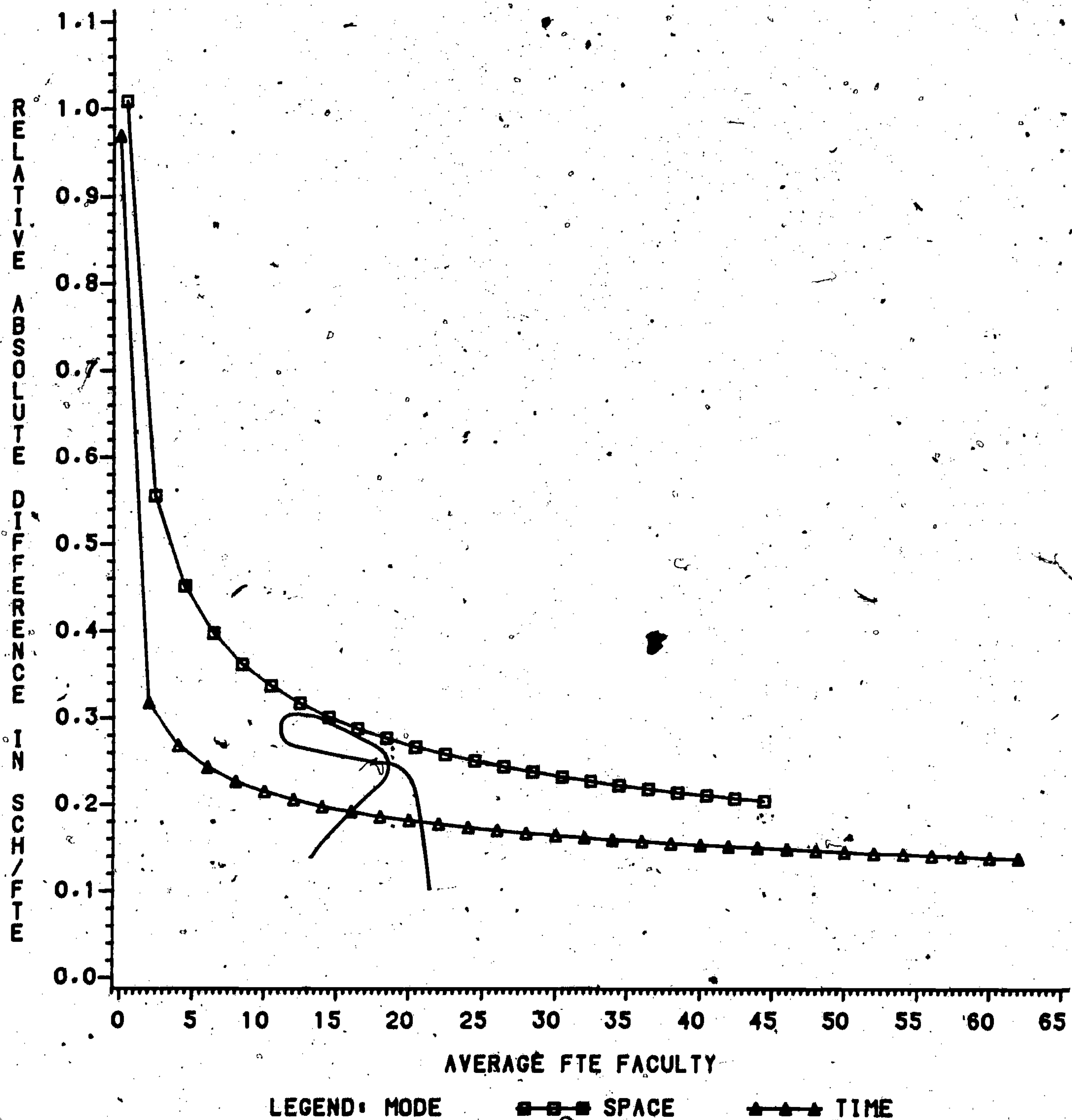


Figure 10

RELATIVE ABSOLUTE DIFFERENCE IN SCH PER FTE FACULTY VERSUS AVERAGE SCH AND AVERAGE FTE FACULTY

Model: $Z = \sqrt{((a/X)^2 + (b/Y)^2)}$. Corr: r = 0.15.

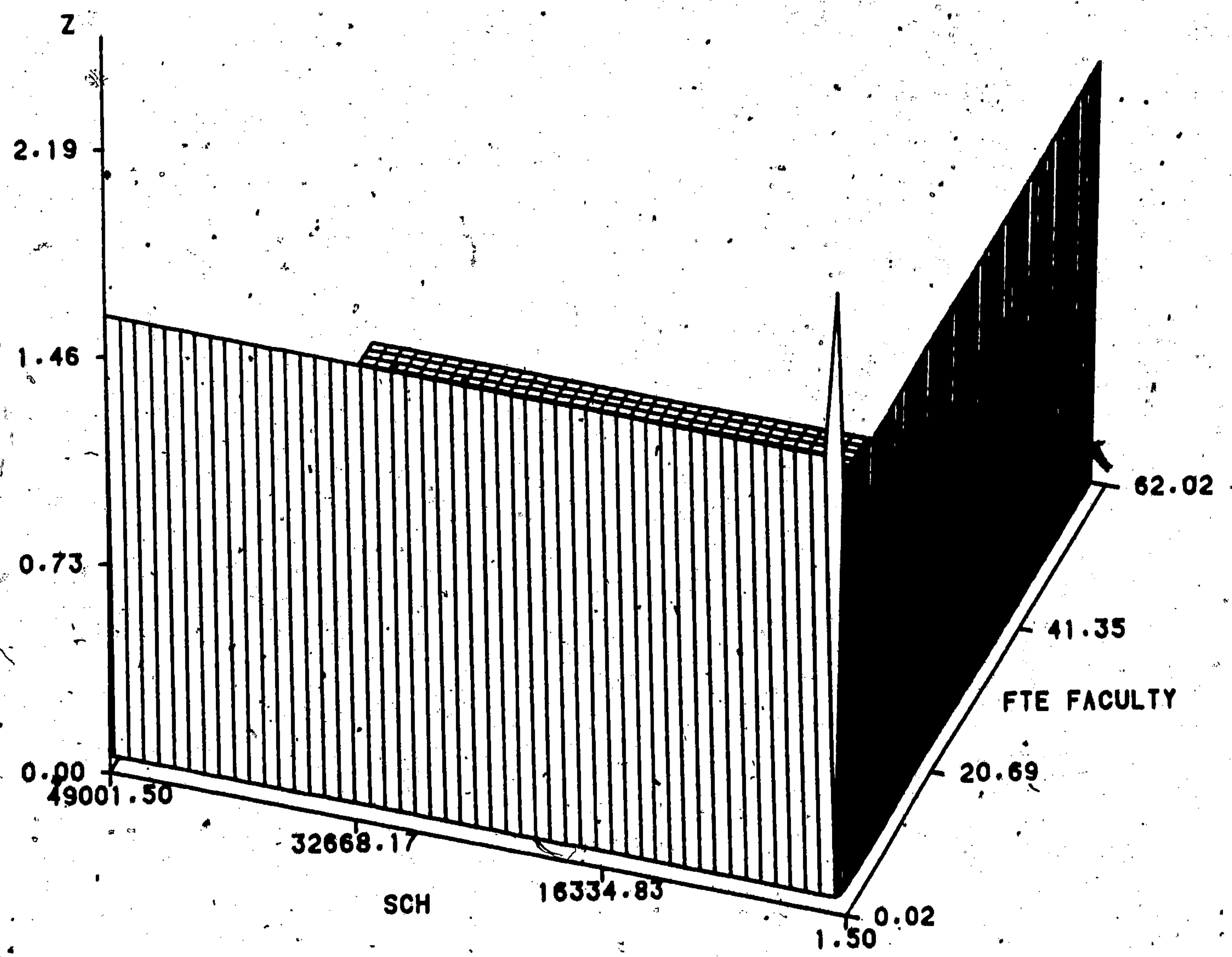


Figure 11

FREQUENCY OF FTE FACULTY VALUES IN VIRGINIA IEP COST CENTERS

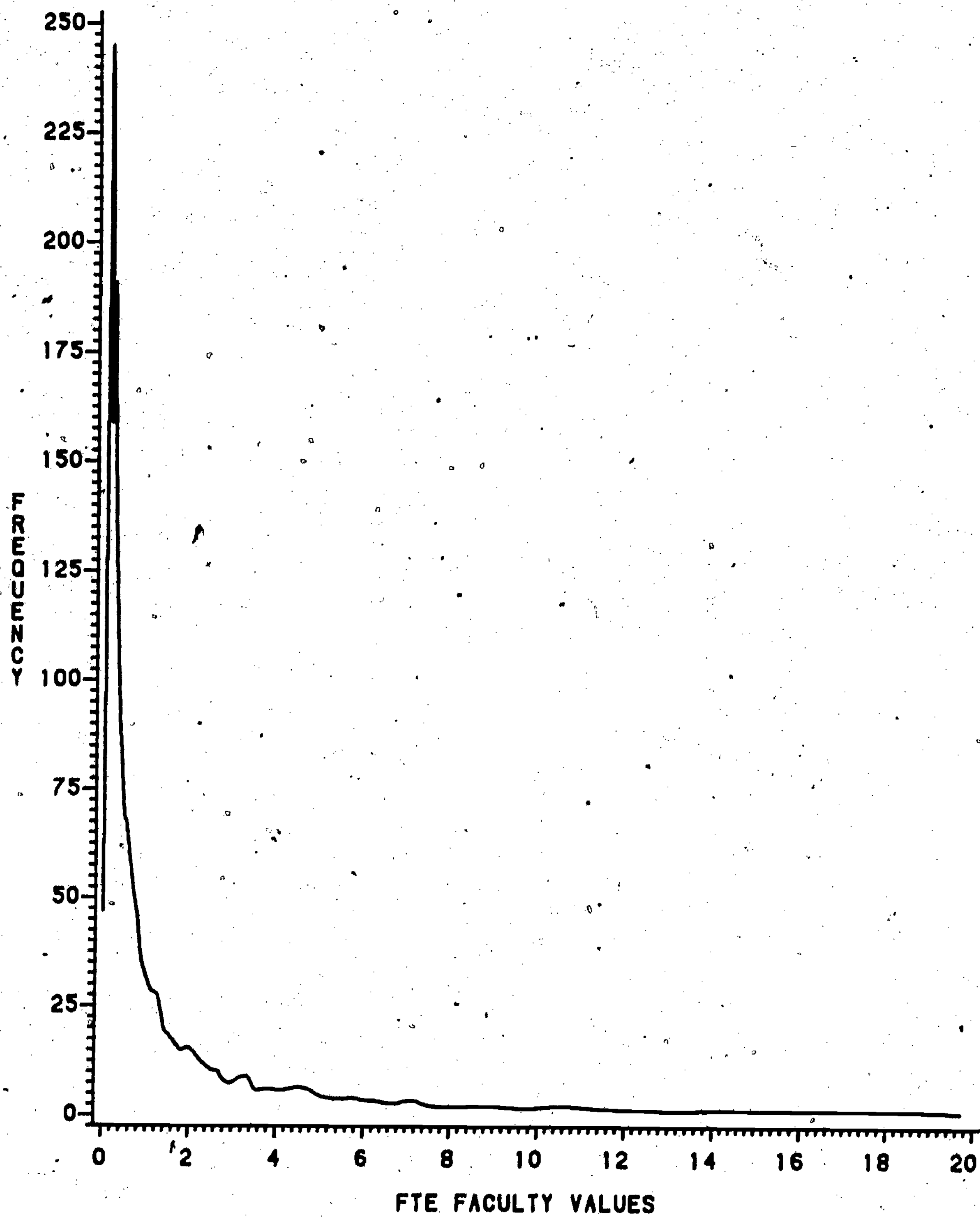
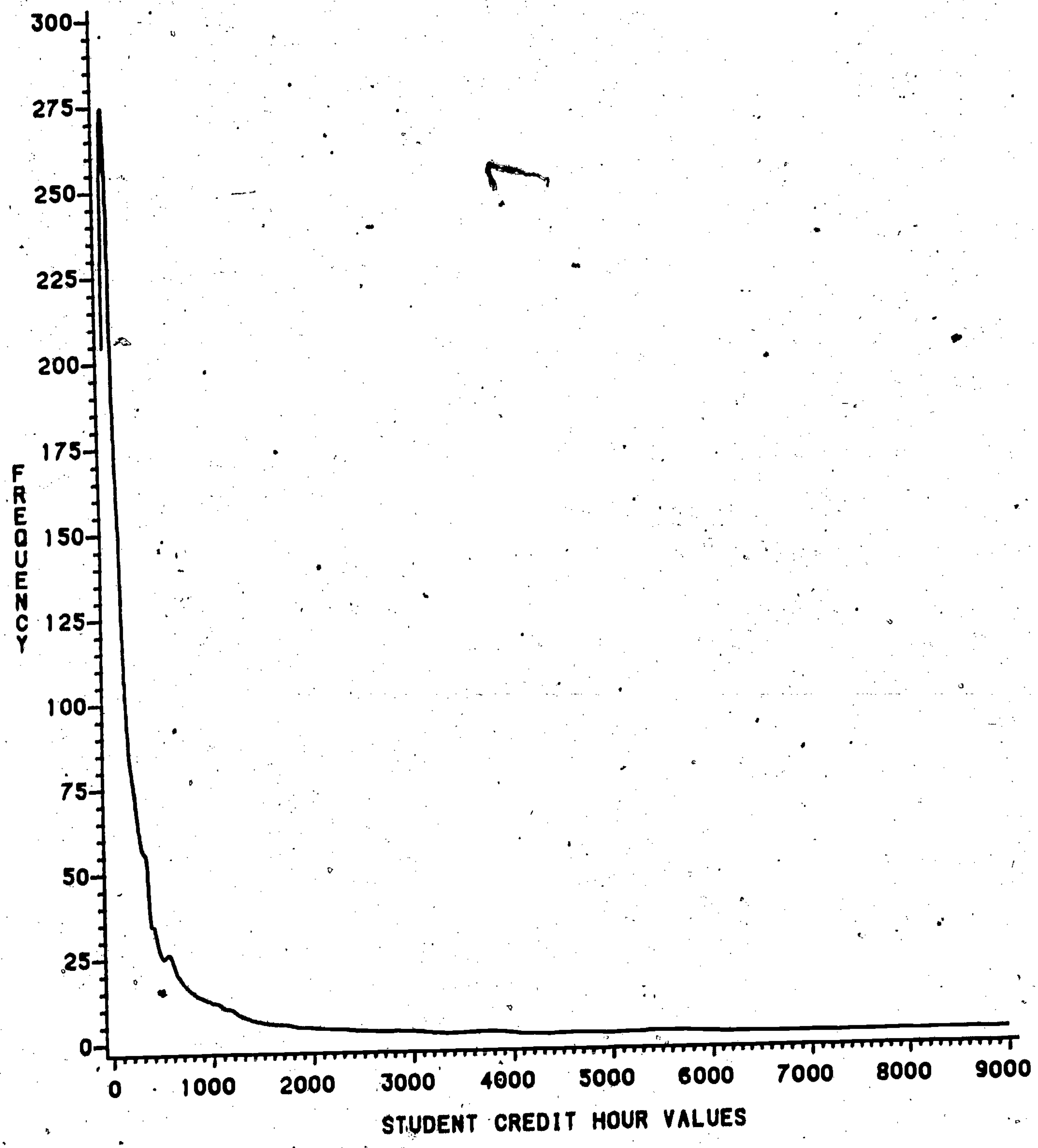


Figure 12

FREQUENCY OF STUDENT CREDIT HOUR VALUES IN VIRGINIA IEP COST CENTERS



Appendix

BASIC MODEL: if $y = f(x)$ and Wy is the uncertainty of y and Wx is the uncertainty of x then

$$Wy = \sqrt{\sum_n \left(\frac{\partial y}{\partial x_i} Wx_i\right)^2}$$

I. Index model

$$Wpr = Wp$$

a. additive $Wp = a$

$$Wpr = a$$

b. multiplicative $Wp = axPR$

$$Wpr = axPR$$

$$Wpr/PR = a$$

II. Ratio model

$$PR = S/F$$

$$Wpr = \sqrt{\frac{1}{F^2}Ws^2 + \left(\frac{S}{F^2}\right)^2 Wf^2}$$

$$Wpr/PR = \sqrt{(Ws/S)^2 + (Wf/F)^2}$$

a. additive $Ws = a;\ Wf = b$

$$Wpr/PR = \sqrt{(a/S)^2 + (b/F)^2}$$

b. multiplicative $Ws = aS;\ Wf = bF$

$$Wpr/PR = \sqrt{a^2 + b^2}$$

III. Component Model

$$S = \sum_n s = n\bar{s} \qquad F = \sum_m f = m\bar{f}$$

$$Wpr = \sqrt{\sum_n (Ws/F)^2 + \sum_m (S \cdot Wf/F^2)^2}$$

$$Wpr/PR = \sqrt{\sum_n (Ws/S)^2 + \sum_m (Wf/F)^2}$$

a. additive $Ws = a;\ Wf = b$

$$Wpr/PR = \sqrt{a^2/n\bar{s}^2 + b^2/m\bar{f}^2}$$

b. multiplicative $Ws = as;\ Wf = bf$

$$Wpr/PR = \sqrt{a\sum_n (s^2)/(\sum_n s)^2 + b\sum_m (f^2)/(\sum_m f)^2}$$

Footnotes

1. When two or more outputs are produced by a single interrelated faculty activity, the costing of these outputs requires a one-to-many, or forked allocation of the jointly incurred cost. For example, when a faculty member works with a Research Assistant on a funded research project, both research and instruction (the outputs) are produced synergistically. Since no theoretical basis exists for tracing these costs, the common practice is to assign costs by arbitrary allocation. The use of course credit hours as a proxy for faculty effort is simply one example of an arbitrary cost allocation mechanism. Unfortunately, the resulting costs associated with each output are simply a function of the arbitrary allocation used, and do not reflect actual resource allocations in the production of the outputs. The reader is referred to Thomas (1982) for a discussion of the joint-cost allocation problems inherent in the attempt to cost the output of faculty activities. Thomas (1980) covers in detail the cost accounting difficulties inherent in the forked allocation of joint-costs including the perverse impact these arbitrary costs can have when used as a basis for internal management decisions. Hopkins and Massey (1981, p. 113) also discuss the importance of considering the joint production process for instruction and research. They concluded that joint production "is absolutely central to the workings of the research university."

2. Based on the low replicability of HEGIS/levels between the two institutions, we chose not to use a two-way ANOVA model as initially planned.

3. If the cost center appeared at both points of time, it is assumed that the estimate to be used would be the mean for all four observations.

4. Dollars were deflated by the Consumer Price Index to 1978 dollars.

5. The average absolute difference is used as a measure related to uncertainty. The experimenter would make statements of confidence that the real number was within ± this amount. These graphs are obtained by regressing the y variable on the x variable and plotting the resulting equation. Detailed results are available from the senior author for a period of two years from the date of publication of this article.

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