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BEFORE THE
POSTAL RATE COMMISSION
WASHINGTON, D. C. 20268-0001

POSTAL RATE AND FEE CHANGES, 2001	Docket No. R2001–1

DIRECT TESTIMONY
OF
A. THOMAS BOZZO
ON BEHALF OF THE
UNITED STATES POSTAL SERVICE

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USPS-LR-J-56 Programs and Electronic Input Data for Mail Processing Volume Variability Analysis

Autobiographical Sketch

My name is A. Thomas Bozzo. I am a Senior Economist with Christensen Associates, which is an economic research and consulting firm located in Madison, Wisconsin. My education includes a B.A. in economics and English from the University of Delaware, and a Ph.D. in economics from the University of Maryland-College Park. My major fields were econometrics and economic history, and I also completed advanced coursework in industrial organization. While a graduate student, I was the teaching assistant for the graduate Econometrics II-IV classes, and taught undergraduate microeconomics and statistics. In the Fall 1995 semester, I taught monetary economics at the University of Delaware. I joined Christensen Associates as an Economist in June 1996, and was promoted to my current position in January 1997.

Much of my work at Christensen Associates has dealt with theoretical and statistical issues related to Postal Service cost methods, particularly for mail processing. In Docket No. R97–1, I worked in support of the testimonies of witnesses Degen (USPS–T–12 and USPS–RT–6) and Christensen (USPS–RT–7). Other postal projects have included econometric productivity modeling and performance measurement for Postal Service field units, estimation of standard errors of CRA inputs for the Data Quality Study, and surveys of Remote Barcode System and rural delivery volumes. I have also worked on telecommunications costing issues and on several litigation support projects. In Docket No. R2000-1, I gave direct and rebuttal testimony on volume-variability factors for mail processing labor costs (USPS-T-15 and USPS-RT-6) and rebuttal testimony on the Postal Service's estimates of costs by weight increment (USPS-RT-18).

Purpose and Scope of Testimony

My testimony is an element of the Postal Service's volume-variable cost analysis for mail processing labor. The purpose of this testimony is to present the econometric estimates of volume-variability factors used in the Postal Service's BY 2000 Cost and Revenue Analysis (CRA) for twelve "Function 1" mail processing labor cost pools. The twelve cost pools represent letter, flat, bundle, and parcel sorting operations at facilities that report data to the Management Operating Data System (MODS). The labor costs associated with those cost pools total $5.255 billion for BY 2000.

The results presented in this testimony update results originally presented in my direct testimony from Docket No. R2000-1, USPS-T-15. The updated analysis incorporates MODS data from two additional Postal Fiscal Years, presents disaggregated BCS and FSM variabilities corresponding to witness Van-Ty-Smith's cost pools, corrects some technical errors identified at the end of the Docket No. R2000-1 proceedings, and implements several minor changes to the previous work. The updates are discussed below.

The economic and econometric theory underlying the analysis is discussed at length in my direct testimony from Docket No. R2000-1, USPS-T-15. Additional discussion as well as detailed responses to numerous critiques of the methodology may be found in my rebuttal testimony from Docket No. R2000-1, USPS-RT-6, and Prof. William Greene's rebuttal testimony, USPS-RT-7.

Library Reference LR–J–56 contains background material for the econometric analysis reported in this testimony. LR–J–56 has three main parts:

(1) descriptions of the computer programs used to estimate the recommended volume-variability factors; (2) descriptions of the computer programs and processing procedures used to assemble the data set used in the estimation procedures; and (3) a description of the methods used to develop MODS productivity data for use by witness Miller (USPS–T–22 and USPS–T–24). The accompanying LR-J-56 CD-ROM contains electronic versions of the econometric computer programs, econometric input data, and full econometric output.

I. Introduction

I.A. Overview and recap of previous research

Few postal costing topics have been more contentious in recent rate proceedings than volume-variability factors for mail processing labor cost pools. A cost pool's volume-variability factor ("variability") is, in economic terms, the elasticity of cost with respect to volume, or the (relative) percentage change in cost that would result from a given percentage change in volume, holding other factors equal. So, if the volume-variability factor for a cost pool is v, and volume increases by X percent, then the resulting percentage increase in costs for that cost pool would be by vX percent. Variabilities are essential inputs into the measurement of marginal (i.e., unit volume-variable) cost and incremental cost for postal products. See LR-J-1, App. H and App. I. Economic theory does not determine specific values for variabilities a priori, so variability measurement is an empirical matter.[1]

The Commission's mail processing cost methodology employs a 100 percent[2] volume-variability assumption, which dates back thirty years to Docket No. R71-1. Prior to Docket No. R97-1, the 100 percent variability assumption was controversial because of the absence of reliable empirical evidence on the actual degree of volume-variability for clerk and mail handler costs. The 100 percent variability assumption for mail processing and distribution activities had been justified prior to Docket No. R97-1 by an empirically unsupported and logically flawed qualitative analysis.[3] It states, in essence, that because distribution workloads ("handling at each work center") vary with volume (to an unspecified degree), mail processing and distribution costs are therefore 100 percent volume-variable. The central flaw in the logic of the 100 percent variability story is that the presence of a positive relationship between mail volumes and mail processing costs does not imply a specific degree of volume-variability. Empirically, while the 100 percent variability story cannot be ruled out *a priori*—just as it cannot be established *a priori*—its statements about the

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[1] Economic theory suggests that costs should be non-decreasing in output, which implies only that variabilities should be positive. A rare point of agreement in Docket No. R2000-1 was that economic theory does not require the degree of volume-variability to be 100 percent. See Docket No. R2000-1, Tr. 27/12989 (Neels); Tr. 27/13212-3 (Smith).

[2] Several mail processing activities are assumed non-volume-variable in the "100 percent variability" method. However, the costs associated with those activities are very small in the cost pools studied here. See Appendix A, Table A-1, below.

[3] The story supporting the 100 percent variability analysis was last presented in Docket No. R97-1, USPS-LR-H-1. That document described the development of the FY 1996 Cost and Revenue Analysis (CRA), the last Postal Service CRA to employ the full 100 percent variability assumption in mail processing.

relationship between processing and distribution workloads and costs are quantitatively testable. If true, the 100 percent variability assumption must manifest itself in the Postal Service's operating data.

Prior to Docket No. R97-1, the mail processing cost analysis was assailed by some intervenors, particularly Periodicals mailers, as providing an inadequate causal basis for the attribution of certain mail processing costs to subclasses. Historically, the Commission rejected ad hoc intervenor proposals to reallocate costs among subclasses or to reclassify portions of mail processing costs as institutional while noting that the costing issues "warrant further investigation" (See, e.g., PRC Op., R94-1, at III-10, III-12).

The Postal Service's investigation of mail processing cost issues led it to examine the empirical validity of the 100 percent volume-variability assumption using the Postal Service's operating data and modern panel data econometrics. Prof. Bradley presented the results of the study in Docket No. R97-1, USPS-T-14. Prof. Bradley's econometric estimates of volume-variability factors showed that the 100 percent assumption dramatically overstated the degree of volume-variability for the cost pools he studied. Prof. Bradley's methods and results were ultimately rejected by the Commission, which cited a raft of issues pertaining to data quality, economic foundations, and econometric panel data methodology (see PRC Op., R97-1, Vol. 2, App. F).

For Docket No. R2000-1, I reviewed the history of and conceptual basis for the 100 percent variability assumption, Prof. Bradley's methods, and the Commission's analysis leading to the rejection of Prof. Bradley's variability estimates. Using documents from Docket No. R71-1, I demonstrated that the

100 percent variability assumption had no foundation in reliable empirical analysis, in that it was employed in lieu of a simple time series analysis of Cost Segment 3 that was explicitly rejected—with good cause—as an appropriate volume-variability analysis. The 100 percent variability assumption also resulted, in part, from the use of an overly restrictive analytical framework in which all cost components were assumed to be either zero or 100 percent volume-variable, and intermediate degrees of volume-variability (between zero and 100 percent) were not admitted. The 100 percent variability assumption was originally adopted in Docket No. R71-1 not because it was shown to be correct empirically, but rather because no other party had presented a viable alternative. See Docket No. R2000-1, USPS-T-15 at 6-9.

I showed that an economic labor demand analysis was an appropriate theoretical framework for the mail processing labor volume-variability analysis, and that Prof. Bradley's "cost equations" could be interpreted as underspecified labor demand functions. I demonstrated that Prof. Bradley's key methodological choices, including the use of panel data estimation techniques at the cost pool level, and of a "flexible" (translog) functional form, were appropriate, and the finer details of the analysis were defensible. I re-estimated the variabilities for a subset of the MODS cost pools analyzed by Prof. Bradley, using a more recent data set, and including additional variables to more fully specify the labor demand functions. The results reinforced the finding that variabilities for the studied cost pools were substantially less than 100 percent. In the absence of supporting empirical evidence, I declined to recommend lower "proxy" variabilities for cost pools without econometric variabilities.

In its Docket No. R2000-1 Opinion, the Commission again rejected the econometric variabilities, and reaffirmed its belief in the 100 percent variability assumption for mail processing labor costs (PRC Op. R2000-1, Vol. 1 at 86-98). The Commission appeared to accept my characterization of the economic framework of the variability models as short-run labor demand functions, and acknowledged that my choice of estimation technique was consistent with my stated assumptions regarding the models (PRC Op. R2000-1, Vol. 2, App. F at 45, 52). However, the Commission objected to many of those assumptions. The Commission maintained its erroneous opposition to the use of the fixed effects model (id. at 46-47, 49-50), and its belief that measurement error in the MODS piece handling data had the potential to cause serious bias to the estimated variabilities (id. at 38-44), notwithstanding testimony to the contrary by Prof. Greene. The Commission found that the econometric treatment of capital (and other variables) as predetermined was incorrect and represented a source of simultaneity bias in the results (id. at 46-48, 52-53), even though no specification tests results indicating the potential for simultaneity bias were presented by any party. Additionally, it incorrectly concluded that the Postal Service's econometric results would indicate massive waste of inputs in mail processing operations (id. at 54-55). Finally, the Commission redeployed an erroneous reliability argument it made in rejecting Prof. Bradley's findings in Docket No. R97-1 , maintaining, contrary to econometric theory, that estimates derived from biased and unbiased models ought to be similar (id. at 55-61). I address many of these criticisms below.

I.B. Postal Service research since Docket No. R2000-1

The scope of the volume-variability analysis for BY 2000 mail processing labor costs is limited by the relatively short time that has elapsed since the end of Docket No. R2000-1. Given the limited time, the Postal Service's efforts have been focused on correcting and updating the labor variabilities for the Function 1 sorting cost pools studied in the last two rate cases. Operationally, those cost pools are well-understood and, as demonstrated below, they pose the fewest substantive methodological difficulties.

Part of the current research effort is a "reality check"—to determine through field observation whether the mail processing activities that are likely to vary less than proportionally with volume (at least over some range of volumes) constitute a sufficiently large fraction of labor time to explain the econometric variabilities. Accordingly, I visited several plants, and observed a wide variety of operations on all three tours. My general observations indicate that container handlings (and other incidental allied labor), setup and takedown, waiting time, and other activities that would be expected to exhibit relatively low degrees of volume-variability represent a substantial proportion of the labor in the operations for which I present econometric variability estimates. My observations are consistent with witness Kingsley's testimony, which reports that setup and takedown time alone constitutes 9 to 12 percent of total runtime in BCS, FSM, OCR, and SPBS operations at two plants in the Washington, D.C. metropolitan area (USPS-T-39 at 31-32).

The activities I observed—discussed at greater length by witness Kingsley (and both witnesses Kingsley and Degen in Docket No. R2000-1) are important because there is a general understanding that costs for those activities exhibit a "stair step" pattern—this was illustrated by Dr. Neels at Docket No. R2000-1, Tr. 27/12822-3. In this pattern, costs are insensitive to small variations in volume as, for instance, containers bound for certain destinations fill, then increase when an additional volume requires an additional container handling. Certainly, an important feature of the stair step pattern is that the costs do not respond proportionally over some range of volumes. However, Dr. Neels argued that the "replication" of an activity, leading to the stair step pattern of costs, would eventually lead to the activity's costs increasing in direct proportion to piece handlings (Tr. 27/12822, 12979-80). As is typical of much of the *a priori* reasoning surrounding the 100 percent variability assumption, Dr. Neels's statement implicitly contains a number of assumptions—that every "tread" of the stair step function has the same width and that every "riser" has the same height, for instance—that are econometrically testable. In general, the slopes of the functions representing the many activities with stair step cost patterns need not be constant, and the elasticity need not be 100 percent. Given that the Postal Service's operating data exhibit ample variation to embody the "replication" effect to whatever extent it is present in Postal Service operations (Tr. 27/12980), if the "replication" effect were to lead to 100 percent variability, the econometric results would so indicate. That they do not indicates that the assumptions needed for 100 percent variability are incorrect.

A second element of the current Postal Service research effort focuses on the appropriate level of disaggregation for the cost pools. A review of the BY 1998 cost pools indicated that it would be desirable to disaggregate the BCS, FSM, and cancellation/metered mail preparation (metered prep) cost pools. Disaggregated BCS and FSM variabilities are incorporated into the Postal Service's BY 2000 CRA. See Sections II.B.3 and III.F, below, for discussion. The cancellation/metered mail preparation cost pool has been dropped from the present study because a disaggregated analysis could not be completed in time for Base Year CRA input deadlines.

Several factors favor a move to a disaggregated analysis for the cancellation and metered prep cost pool. The aggregated cost pool inherently combines several distinct operations and technologies, including hand cancellations, AFCS, and metered prep operations. The aggregation is problematic because the composition of the cost pool has shifted substantially between FY 1996 and FY 2000. During that time, total workhours in the cost pool dropped by 839,902 hours while the absolute number of workhours in the highest productivity operation, AFCS (MOD 015) increased by 346,322 hours. As a result, the AFCS share of workhours in the cost pool increased from 16.6 percent in FY 1996 to 20.7 percent in FY 2000.[4] The change in composition towards higher productivity operations could be mis-measured as a low degree of volume-variability in an aggregated analysis. Preliminary results yield variabilities of 58 percent for mechanized cancellation operations and 64 percent for AFCS (operation 015) alone.[5]

I anticipate that the Postal Service will present a more comprehensive analysis in a future proceeding, encompassing LDC 17 allied labor operations

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[4] See Docket No. R97-1, LR-I-146 at I-19; Docket No. R2001-1, LR-J-55 at I-20.

[5] See LR-J-56, program varnl-cancmpp.tsp.

(e.g., platform, opening, in addition to cancellation and metered prep), BMC operations, and operations at post offices, stations and branches (e.g., Function 4 MODS and non-MODS operations). Pending analysis of the remaining cost pools not covered by this study, the Postal Service's BY 2000 CRA continues to apply the 100 percent variability assumption to those cost pools. As was the case in the BY 1998 CRA, the 100 percent variability method is used with significant reservations. See Docket No. R2000-1, USPS-T-15 at 132-139.

As a final element of research since Docket No. R2000-1, I reviewed the economic and econometric criticisms in the Commission's Docket No. R2000-1 Opinion and Recommended Decision. Upon review, I determined that the Commission repeated some key econometric errors from Docket No. R97-1. In addition, many of the Commission's new criticisms, such as the criticisms of the wage variable and capital elasticities, either mischaracterized or misinterpreted my Docket No. R2000-1 analysis. See Sections II and IV, below, for additional discussion. I view Prof. Greene's rebuttal testimony from Docket No. R2000-1, USPS-RT-7, as authoritative on the matter of appropriate econometric methodology. Accordingly, many of the central elements of the BY 1998 study are present in the current analysis, most notably the continued use of disaggregated labor demand models estimated using panel data fixed effects techniques. Changes to the BY 1998 methodology, which include the correction of technical errors identified by Dr. Neels late in Docket No. R2000-1, are detailed in Section III. The BY 2000 labor demand models and results are presented in Section IV.

II. The Postal Service's Volume-Variability Methods for BY 2000 Mail Processing Labor Costs

II.A. Economic theory issues

II.A.1. Economic cost theory underlying the analysis

The volume-variability analysis for mail processing labor cost pools is grounded in economic cost minimization theory.[6] In the basic formulation of the cost minimization problem, the firm chooses the quantities of "variable" inputs that produce a given level of output at minimum cost, subject to the firm's production function, the available amounts of "quasi-fixed" inputs, and any other relevant factors that may serve as constraints (and hence explain costs).[7] The use of the term "quasi-fixed"—as opposed to simply "fixed"—indicates that the quasi-fixed inputs need not be constant over time. Rather, the quasi-fixed inputs are merely those inputs that are taken as given when the quantities of the variable inputs are chosen.

The resulting cost function is a function of the level of output, the price(s) of the variable input(s), the quantities of the quasi-fixed inputs (if any), and the other factors that explain costs. Associated with the cost function is a set of factor demand functions that depend on the same set of variables, from which

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[6] As I discussed in my Docket No. R2000-1 testimony, however, neither my analysis nor Dr. Bradley's requires the assumption that the Postal Service's plans and procedures are cost minimizing. A generalized non-minimum cost function would lead to the same conclusions. Docket No. R2000-1, USPS-T-15 at 32-34.

[7] This describes the "short run" cost minimization problem. The "long run" analysis is the case in which there are no quasi-fixed inputs.

the output elasticities (i.e., variabilities) can be derived. For mail processing labor variabilities, the utility of employing the factor demand function approach, as opposed to directly estimating the cost function, is that the quantity of labor demanded (workhours) by cost pool is readily observable whereas labor cost is not available at the cost pool level.[8]

The Commission's analysis incorrectly implies that the treatment of mail processing capital as quasi-fixed in the short run conflicts with the assumption that mail processing capital costs are volume-variable (to some degree) over the rate cycle (PRC Op., R2000-1, Vol. 2, App. F at 26; 48). There is no dispute that over longer periods such as the "rate cycle," capital input is both variable (in the sense of being non-constant) and volume-variable to some degree.[9] However, the long-run variability of capital costs does not imply that capital cannot be quasi-fixed in the short run. To the contrary, the general economic scheme is that inputs that are quasi-fixed in the short run may vary over the "longer run," and vice-versa.[10] The Commission erred when it characterized my econometric model as assuming that "the capital equipment found in... mail processing plants is fixed for the duration of the rate cycle" (PRC Op. R2000-1, Vol. 2, App. F at 26). I make no such assumption, as Prof. Greene recognized (Tr. 46-E/22063-4). The treatment of capital as quasi-fixed for a postal quarter simply recognizes

[8] Significant additional complications would arise in imputing total cost (labor and non-labor) by cost pool.

[9] Indeed, in Docket No. R2000-1, I presented the economic rationale for treating mail processing capital costs as volume-variable to the same degree as the corresponding labor costs in the absence of a formal capital variability analysis (Docket No. R2000-1, USPS-T-15 at 39-41).

[10] See, e.g., Hal R. Varian, *Microeconomic Analysis, Third Edition*, New York: Norton, 1992, pp. 2-3.

that plant management cannot freely obtain or dispose of capital in such a short time period. It does not require capital to be constant over the rate cycle.

Furthermore, longer-term capital input decisions necessarily precede the staffing decisions they eventually affect (see Docket No. R2000-1, Tr. 46-E/22185-6). Thus, to whatever extent capital and labor are "endogenous" over lengthy time horizons, they are not determined simultaneously.

In Docket No. R2000-1, witness Degen observed that the rollforward process involves—among other things—adjusting Base Year costs to account for the effects of deploying new equipment and other planned operational changes (Docket No. R2000-1, USPS-T-16 at 9-10). Therefore, it is appropriate for Base Year mail processing labor costs to be "short-run" in the sense of being conditioned on Base Year operating procedures. Otherwise, incorporating longer-run cost adjustments into the Base Year mail processing CRA, without eliminating those adjustments from the rollforward process, would double-count the effects of those adjustments. As a practical matter, though, the small magnitudes of the capital elasticities from the mail processing labor demand models mean that specifying long-run elasticities instead of short-run elasticities does not alter the central result that mail processing labor costs are less than 100 percent volume-variable.[11]

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[11] The long-run elasticities can easily be derived from the results of the short-run model using the relationship $\varepsilon_{L,Q}^{LR} = \varepsilon_{L,Q}^{SR}/(1-\varepsilon_{L,K})$, where $\varepsilon_{L,Q}^{LR}$, $\varepsilon_{L,Q}^{SR}$, and $\varepsilon_{K,Q}$ are, respectively, the long-run output elasticity, the short-run output elasticity, and the capital elasticity (the latter two derived from the short-run labor demand function). For a derivation see R. H. Spady, *Econometric Estimation for the Regulated Transportation Industries*, New York: Garland Publishing, 1979.

II.A.2. The Postal Service's methodology correctly applies the "distribution key" approach to volume-variable cost estimation

The Commission has claimed that Dr. Neels's R2000-1 analysis of the relationship between total pieces fed (TPF)[12] and first handling pieces (FHP) casts "serious doubt" on the validity of the Postal Service's application of the distribution key method, which embodies what has been termed the "proportionality assumption" (PRC Op., R2000-1, Vol. 2, App. F at 62-63). In Docket No. R2000-1, I noted that the "proportionality assumption" represented a mathematical approximation between unit volume-variable cost and marginal cost, which is exact under special circumstances, and thus involved no bias. I further testified that, because failure of the proportionality "assumption" represented only an approximation error, Dr. Neels had been correct to observe, in Docket No. R97-1, that there was no obvious direction of bias (Docket No. R2000-1, USPS-T-15 at 53-55). Since the Commission appears to doubt that deviations from the "proportionality assumption" represent an approximation error, I derive the mathematical result that establishes my previous claim below.[13]

Dr. Neels's analysis in Docket No. R2000-1 presented an adjustment to the variabilities[14] in which he econometrically estimated elasticities of TPF with respect to FHP using a "reverse regression" procedure, and employed the FHP

[12] For manual operations, the total pieces handled (TPH) variable is equivalent to TPF. For additional discussion of MODS workload measures, see Docket No. R2000-1, USPS-T-15 at 50-53.

[13] Some of these results may be found in Appendix H of LR-J-1, and in the Docket No. R97-1 rebuttal testimony of Dr. Christensen, USPS-RT-7.

[14] Adjustments were made to both the Postal Service's recommended variabilities and Dr. Neels's alternative "shapes-level" variabilities.

elasticities as multiplicative adjustment factors for the variabilities (Tr. 27/12832, 12902-3). Prof. Greene and I demonstrated that the econometric component of Dr. Neels's analysis was—at least by the standards applied by the Commission to the Postal Service's variability studies—fatally flawed. Prof. Greene showed that the "reverse regression" procedure employed by Dr. Neels was intrinsically biased, independent of the measurement error problem that Dr. Neels's procedure purported to address (Tr. 46-E/22068-71).[15] I showed that Dr. Neels's reverse regression elasticities were, additionally, mis-specified in that they could not be derived from the "direct" relationship between TPF and FHP (Tr. 46-E/22165-8).[16]

I also noted that Dr. Neels's adjustment inappropriately equated FHP, a MODS workload measure, with RPW volume. Thus, it was incomplete in that it omitted a term—neglected by both Dr. Neels and the Commission in its analysis—relating FHP and RPW volume. The omitted term is required to produce meaningful volume-variable cost estimates (Tr. 46-E/22162).

The mathematics of volume-variable costs and the distribution key method demonstrate that Dr. Neels's FHP adjustment is irrelevant. To state the result (shown mathematically below) in advance of the derivation, the effect of the omitted term relating FHP and RPW volume, needed to correctly apply Dr. Neels's FHP adjustment, is to cancel out Dr. Neels's FHP elasticity adjustment to

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[15] It should be noted that Dr. Neels did not testify that the reverse regression procedure produced unbiased estimates or otherwise constituted a statistically appropriate technique.

[16] That is, since $TPF = f(FHP)$, the elasticity $\partial \ln TPF / \partial \ln FHP = \partial \ln f(FHP) / \partial \ln FHP$ is a function of FHP, whereas Dr. Neels's reverse regression elasticities are functions of TPF.

a first approximation. Since the FHP adjustment is unnecessary, it is also unnecessary to attempt to remedy the econometric flaws of Dr. Neels's "reverse regression" analysis of the relationship between TPF and FHP.

The volume-variable cost of subclass *j* in cost pool *i* is defined as the product of the marginal cost of subclass *j* in cost pool *i* and the RPW volume of subclass *j*:

$$VVC_{i,j} \equiv MC_{i,j} V_j \,, \tag{2}$$

where

$$MC_{i,j} = \partial C_i / \partial V_j \,. \tag{3}$$

Because of the limited availability of time series data on volumes, directly estimating marginal costs using equation (3) is not feasible.[17] However, with some elementary calculus, the problem can be decomposed into feasible components. Since data on the intermediate outputs ("cost drivers") are available, the usual decomposition of marginal cost is given by equation (4):

$$\partial C_i / \partial V_j = \partial C_i / \partial D_i \cdot \partial D_i / \partial V_j \,, \tag{4}$$

which shows that the marginal cost can be rewritten as the product of the marginal cost of the intermediate output and the marginal contribution of RPW volume to the intermediate output. Equation (4) can be rewritten in terms of elasticities as follows:

$$\partial C_i / \partial V_j = (C_i / D_i \cdot \varepsilon_i) \cdot (D_i / V_j \cdot \delta_{ij}) = C_i \varepsilon_i \delta_{ij} / V_j \,, \tag{5}$$

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[17] The implicit cost function generally would have many more parameters than there are observations given the number of CRA subclasses. Of course, all the usual difficulties of reliably estimating multivariate regressions from pure time series data would also be present.

where $\varepsilon_i = \partial \ln C_i / \partial \ln D_i$ is the elasticity of cost with respect to the cost driver in cost pool *i* (i.e., the variability for cost pool *i*), and δ_{ij} is the elasticity of the cost driver with respect to RPW volume. Substituting equation (5) into (2) gives:

$$\Rightarrow VVC_{i,j} = C_i \varepsilon_i \delta_{ij}. \tag{6}$$

Equation (6) is the "constructed marginal cost" formula from Appendix H of LR-J-1.

Implementing equation (6) to measure volume-variable costs is generally not feasible either, as the RPW volume time series are inadequate to estimate the function relating RPW volumes to the cost driver and thus δ_{ij}. Accordingly, the Postal Service approximates the elasticities δ_{ij} with "distribution key shares" $d_{ij} = D_{i,j} / D_i$, representing the proportions of the cost driver by subclass. The substitution of the distribution key for the elasticity δ_{ij} leads to the "distribution key method" for computing volume-variable cost, which approximates marginal cost:

$$VVC_{i,j} = C_i \varepsilon_i d_{ij} \cong MC_{i,j} \cdot V_j. \tag{7}$$

The distribution key formula can be shown to be equivalent to the constructed marginal cost formula when the function relating the RPW volumes to the cost driver, $D_i = g_i(V_1, \ldots V_N)$, is linear in volumes, in which case both equalities in (7) would be exact.[18] This is the essence of the so-called "proportionality assumption." The "assumption," however, is more appropriately termed a first-order approximation, as one can always write:

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[18] To see this, note that the higher order terms in equation (8) would be identically zero with $g_i(V_1, \ldots V_N)$ linear, so the approximations in equations (9) and (10) would hold exactly.

$$g_i(V_1,\ldots,V_N) = \sum\nolimits_{j=1}^{N} \alpha_{i,j} V_j + O(V^2) \tag{8}$$ [19]

or

$$g_i(V_1,\ldots,V_N) \cong \sum\nolimits_{j=1}^{N} \alpha_{i,j} V_j \tag{9}$$

to a first approximation. The interpretation of the parameters a_j is units of the cost driver (TPF) per RPW piece. The approximate elasticity from equation (9) is:

$$\delta_{ij} = \partial \ln g_i(V_1,\ldots,V_N)/\partial V_j \cong \alpha_{ij} V_j \Big/ \sum\nolimits_{j=1}^{N} \alpha_{ij} V_j = D_{i,j}/D_i\,. \tag{10}$$

Equation (10) establishes that the distribution key method produces unit volume-variable costs that constitute a first approximation to marginal costs. Note that FHP need not be invoked in the derivation.

To introduce Dr. Neels's FHP adjustment term, the elasticity of TPF with respect to FHP (say, $\phi_i = \partial \ln D_i / \partial \ln F_i$), it is necessary to further decompose the term $\partial D_i / \partial V_j$ from equation (4), which leads to:

$$\partial C_i/\partial V_j = \partial C_i/\partial D_i \cdot \partial D_i/\partial F_i \cdot \partial F_i/\partial V_j\,, \tag{4'}$$

or in elasticity terms:

$$\partial C_i/\partial V_j = (C_i/D_i \cdot \varepsilon_i)\cdot(D_i/F_i \cdot \phi_i)\cdot(F_i/V_j \cdot \eta_{ij}) = C_i \varepsilon_i \phi_i \eta_{ij}/V_j \tag{5'}$$

$$\Rightarrow VVC_{ij} = C_i \varepsilon_i \phi_i \eta_{ij}\,, \tag{6'}$$

where the additional term η_{ij} is the elasticity of FHP with respect to RPW volume.

I noted in Docket No. R2000-1 that Dr. Neels's analysis sheds no light on η_{ij} (Docket No. R2000-1, Tr. 46-E/22162). However, the results derived above imply that the additional term neglected by Dr. Neels must, to a first

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[19] The term $O(V^2)$ denotes terms involving squares and higher-order terms in $V = V_1,\ldots,V_N$. In the Taylor series approximation, the parameters a_j are chosen so that at the actual volumes $V^* = V_1^*,\ldots,V_N^*$, $O(V^2)\big|_{V=V^*} = 0$.

approximation, cancel out his FHP adjustment. This result may be shown by combining equations (6) and (6'), which gives:

$$\delta_{ij} = \phi_i \cdot \eta_{ij} . \tag{11}$$

The approximation result from equation (10) implies

$$d_{ij} \cong \phi_i \cdot \eta_{ij} \tag{12}$$

or

$$\eta_{ij} \cong d_{ij} / \phi_i . \tag{13}$$

Finally, substituting (13) into (6'), we obtain:

$$VVC_{ij} \cong C_i \varepsilon_i \phi_i d_{ij} / \phi_i = C_i \varepsilon_{ii} d_{ij} , \tag{14}$$

the rightmost term of which is the same as equation (7), establishing the result that properly applying FHP elasticities in the calculation of volume-variable costs would have (to a first approximation) no effect on the measured costs.

II.B. Econometric issues

II.B.1 The Commission repeated its previous errors in assessing the robustness of the variability models

In its Docket No. R2000-1 Opinion, the Commission stated that in evaluating econometric estimates it:

> relies not only upon the usual statistical measures of goodness-of-fit and significance, but also upon less formal demonstrations that the estimates are robust and stable. In practice these demonstrations of robustness and stability usually take the form of comparisons of results between alternative models, data sets or estimators. (PRC Op. R2000-1, Vol. 2, Appendix F at 55)

The Commission's use of informal robustness checks to evaluate the econometric estimates is appropriate only up to a point. Robustness checks are appropriate to deal with data handling and model selection decisions that are difficult to subject to formal testing but would not be expected to significantly alter the results. However, there is no general expectation of robustness in econometric theory. In particular, theory dictates that the results of an econometric analysis, in general, will not be robust to mis-specification of the model.[20] *In comparing a restrictive model that fails a specification test to a more general model, or comparing a biased model to an unbiased model, "non-robustness" of the results is the expected outcome.* In such cases, non-robustness is appropriately interpreted as favoring the more general model, or the unbiased model.

Consequently, the Commission has erred, in both its R97-1 and R2000-1 opinions, in finding the Postal Service's variability results to be defective because they were not "stable" to a change in estimation method from fixed effects to the pooled OLS model or to other biased estimation methods.[21] The fixed effects model is more general than the pooled OLS model; pooled OLS is a special (restricted) case of the fixed effects model where all of the site-specific constants

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[20] For example, discussing omitted variables bias, Schmidt notes that "it should... be clear that least squares applied to the misspecified equation will not have desirable properties" such as consistency and unbiasedness. Peter Schmidt, *Econometrics* (Marcel Dekker, 1976) at 39. The expected difference between the mis-specified model and a correctly specified model would be the amount of the bias, not zero.

[21] PRC Op. R97-1, Vol. 1 at 67; PRC Op. R2000-1, Vol. 2, App. F at 55-59. Other statistically rejected and/or biased models in Docket No. R2000-1 include the "Model B" (time effects only) specification from NOI No. 4 (see Tr. 46-E/22247) and the models adjusted with results from Dr. Neels's reverse regression analysis (see Tr. 46-E/22068-71, 22159-71), shown by Prof. Greene to be biased independent of presence of measurement error.

are assumed to be the same (i.e., pooled). Whenever the OLS model is unbiased, the fixed effects model is also unbiased. Additionally, the fixed effects model is unbiased if the pooling assumption is false, but the conditions for OLS to be unbiased are otherwise satisfied.[22] Since the pooling assumption has been decisively rejected by standard specification tests, the pooled OLS model is seriously mis-specified and therefore will generally be biased. That the results from the fixed effects model are "sensitive" to the mis-specification of pooled OLS is not a flaw of the fixed effects models, but merely a confirmation of the specification test results that indicate that the pooled OLS estimates are biased.

II.B.2. The panel data fixed effects model is the appropriate econometric framework

In its Docket No. R97-1 Opinion, the Commission rejected Prof. Bradley's analysis in part because it believed that the facility-specific latent variables (i.e., "fixed effects") for which Prof. Bradley's analysis controlled were likely to be volume-variable (PRC Op., R97-1, Vol. 1 at 73, 87-88). In Docket No. R2000-1, I noted that the Commission's position was self-contradictory (Docket No. R2000-1, USPS-T-15 at 34-35). The "fixed effects" are the effects of site-specific latent (unobserved) variables that are literally fixed (i.e. mathematically constant) over the sample period—a fact which is clear from the "dummy variable" formulation of the fixed effects model, where the dummy variable regressor associated with the

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[22] There are also situations in which both fixed effects and pooled OLS may be biased, in which case a robustness check cannot discern the correct model.

"fixed effect" for site *i* is constant for all observations on that site.[23] The "fixed effects" are, therefore, nonresponsive to volume (or any other variable that varies over time) by construction. The Commission's argument in Docket No. R97-1 amounted to the claim that latent variables that are constant over the sample period are somehow volume-variable.

Given that the fixed, site-specific latent variables are inherently non-volume-variable, and that they have been shown to have statistically significant effects on workhours (see Section IV.C.1, below; see also Docket No. R97-1, USPS-T-14 at 41-43, Docket No. R2000-1, USPS-T-15 at 122-124), it follows that the fixed effects model is econometrically appropriate.[24] Likewise, Prof. Greene concluded:

> The Commission should have taken a much more favorable view [of the fixed effects model] in 1997 [*sic*], and should at this time consider the panel data, fixed effects form of econometric analysis an appropriate platform for continuing work on developing a model for mail processing costs. (Docket No. R2000-1, Tr. 46-E/22040 [USPS-RT-7 at 5])

In the Docket No. R2000-1 Opinion, the Commission cites my claim that it made a logical error in concluding that the fixed effects are volume variable and, in trying to explain its reasoning, proceeds simply to repeat the error in its analysis. The Commission claims that my assertion "would be true if the Postal Service's mail processing system was completely static." (PRC Op., R2000-1, Vol. 2, App. F at 71). However, the Commission claims that since the mail

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[23] That is, for all $t = 1, \ldots T$, $d_{j,t} = 1,\ j = i;\ d_{j,t} = 0,\ j \neq i$.

[24] The fixed effects model is consistent (but inefficient) if the random effects model is appropriate.

processing system is "not static," the "fixed effects will change" as the system evolves (*id.*) The self-contradiction is obvious—if the "fixed effects" could change over time, they would no longer be fixed (i.e., time-invariant). The Commission, in order to reach its conclusion that the fixed effects represent an "omitted source of volume variability" (*id.*), must mistakenly attribute to the "fixed effects" the ability to control for both factors that are fixed over time and factors such as the purported indirect volume effects that cannot be fixed over time. In fact, the fixed effects, as the Commission recognized in Docket No. R97-1 (see PRC Op., Docket No. R97-1, Vol. 2, App. F at 41), only control for the fixed (time-invariant) factors. Consequently, as Prof. Bradley and I have maintained, they cannot represent non-fixed, volume-driven factors.

The Commission's contention that the use of a fixed effects model is problematic because the specific nature of the fixed latent variables is unknown (PRC Op., R2000-1, Vol. 2, App. F at 49) also misstates the real econometric problem. The problem—described in most treatments of panel data econometrics[25]—is not that the fixed latent variables are unknown *per se*, but rather that when latent variables are present, econometric methods that fail to control for their effects such as pooled OLS will generally be biased.[26] The advantage of the fixed effects model is precisely that it provides a means of

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[25] See, e.g., Cheng Hsiao, *Analysis of Panel Data*, Econometric Society Monographs No. 11, Cambridge, UK: Cambridge University Press, 1986, pp. 3-5.

[26] This statement is, of course, also true of estimation methods, such as the group means regression ("between model"), that are inherently unable to control for site-specific latent variables. See also Docket No. R2000-1, USPS-T-15 at 67-71; Docket No. R97-1, USPS-T-14 at 39-46.

resolving or reducing the magnitude of the omitted variables bias that would result if the latent variables were simply ignored.

II.B.3. A disaggregated cost pool-level analysis is appropriate

The BY 2000 variabilities are derived from labor demand models estimated at the cost pool level. The MODS-based cost pools studied here aggregate three-digit MODS operations by sorting technology for automated and mechanized operations, and by shape of mail (class, for Priority Mail operations) for manual sorting. The BY 2000 analysis is carried out at a finer level of disaggregation than its BY 1996 and BY 1998 predecessors, since the recommended results disaggregate the BCS and FSM cost pools by equipment type, as described in Section III.F, below.

Given the availability of disaggregated data, the preference for disaggregated or functional analysis is well grounded in econometric theory, as was articulated by Prof. Greene in Docket No. R2000-1. A disaggregated analysis "cannot make things worse" than an aggregated approach and "will give the right answer whether or not [the aggregated] approach is correct" (Docket No. R2000-1, Tr. 46-E/22067-8). By design, the mail processing labor cost pools used in the variability analysis are homogeneous in the sorting technology employed.[27] In contrast, the aggregated models explored by UPS witness Neels in Docket No. R2000-1 explicitly combine heterogeneous sorting technologies

[27] By extension, the cost pools will also be relatively homogeneous in the marginal cost (or productivities) of the sorting activities therein.

within a shape-based mailstream (in the case of the "shape-level" models) or all mail processing activities (in the case of the aggregate time series model).[28]

Fundamentally, the aggregated analyses assume that the aggregate variabilities (singular variability in the case of the Dr. Neels's time series analysis) apply to each cost pool entering into the aggregated group. Since, in theory, the disaggregated variabilities could vary by cost pool, aggregation amounts to a restriction that the disaggregated (cost pool) variabilities be identical. As Prof. Greene noted, "If it were appropriate to aggregate the data…then the aggregate and the disaggregated approaches would produce similar estimates of the [variabilities]" (Docket No. R2000-1, USPS-RT-7 at 32). If the restriction were true, then the cost pool variabilities (estimated without imposing the restriction) would be statistically indistinguishable from the aggregate variability.

To the extent that the cost pool variabilities differ from the aggregate variability, it constitutes evidence that the aggregation is inappropriate because it embodies an incorrect restriction at the cost pool level. Thus, the correct interpretation of statistically significant differences between cost pool (disaggregated) and aggregate variabilities is that "the aggregated approach is causing the problem" (Docket No. R2000-1, USPS-RT-7 at 32). The observed heterogeneity of the cost pool variabilities indicates that aggregated models should be rejected.

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[28] Furthermore, the aggregate time series approach has previously been rejected by the Commission for use in other cost components (see, e.g., PRC Op., R87-1, Vol. 1, ¶3265-6; PRC Op., R90-1, Vol. 1, ¶3192) for essentially the reasons Prof. Greene and I put forth in Docket No. R2000-1 (see Docket No. R2000-1, USPS-RT-6 at 1-2, USPS-RT-7 at 32).

The main econometric advantage to the disaggregation is that it mitigates potential biases from pooling operationally distinct equipment types for analysis. For example, if a researcher were to aggregate operations with different productivities while the composition of the aggregate shifted towards the higher (lower) productivity operations, the composition change could be misinterpreted as suggesting a low (high) degree of volume-variability. This scenario likely explains why, in Docket No. R2000-1, Dr. Neels's aggregated "shapes-level" variability for letter sorting was significantly lower than the disaggregated variabilities I presented for the letter sorting cost pools.

The expansion of automated delivery point sequencing of letters generally increased letter TPF while the shift from low-productivity LSM to high-productivity BCS processing restrained the growth of workhours. Without adequate controls for the composition of operations, the relatively rapid increase in letter TPF relative to workhours could be readily misinterpreted as low volume-variability, when the actual shift was from the low productivity/high variability LSM operation to the high productivity/high variability BCS operation, as my models imply. The reverse is true, to some extent, of the FSM cost pool, where the composition shift of the aggregate FSM group towards the FSM 1000 lowers the aggregate productivity.[29]

The preceding discussion suggests strongly that it is desirable to analyze the volume-variability of the relatively high productivity AFSM 100 operations separately from other FSM operations to avoid introducing an aggregation bias in

[29] Note that FSM 1000 productivity is higher, on average, than the manual flats productivity. The FSM 1000 supplants manual distribution for "nonmachinable" flats.

the FSM variabilities. Likewise, it favors the planned separation of the AFCS operation from other cancellation operations, discussed in Section I.B, above.

II.B.4. Issues pertaining to the choice of functional form

The recommended estimating equations for the labor demand functions use the translog functional form. The principal advantages of the translog functional form were summarized quite well by the Commission itself in Docket No. R87-1 (in the context of modeling purchased transportation costs):

> [T]he translog model can be considered the source for [log-linear] models. That is, they [log-linear models] are simplified derivations from it [the translog model]... [The translog model's] flexibility permits it to follow the relationship between cost and the factors affecting costs in any pattern. That is, unlike the more simplistic models, it does not constrain the results to follow a linear or particular curvilinear arrangement, but instead follows whatever functional form the data show. (PRC Op., R87-1, Vol. 1, ¶ 3543)

Notwithstanding the fact that it has found simpler models than the translog to be inadequate for other cost segments, the Commission suggested in Docket No. R2000-1 that in using the translog, I had inappropriately failed to consider simpler functional forms that have a "long record of successful use in demand studies" (PRC Op., R2000-1, Vol. 2, App. F at 50).[30]

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[30] Historically, the use of simpler functional forms such as the log-linear model was primarily a matter of necessity. When Cobb and Douglas introduced their log-linear functional form in 1928, most computations were done by hand or with mechanical calculators. The computation and memory requirements of high order multivariate regressions such as those required by the use of the translog and other flexible functional forms were prohibitive prior to the widespread availability of digital (mainframe) computers. See, e.g., Ernst R. Berndt, *The Practice of Econometrics: Classic and Contemporary*, Reading, MA: Addison-Wesley, 1991, pp. 450-452.

While the more restrictive nature of simpler functional forms is likely to render them unacceptable, it is an empirical matter whether those restrictions are warranted. Accordingly, I tested the translog functional form against the simpler log-linear functional form. I present results of the tests, which reject the simpler model in favor of the translog, in section IV.C.1, below.

As an additional check on the sensitivity of the results to the choice of the translog form, I also re-estimated a subset of the variabilities using the generalized Leontief functional form.[31] The generalized Leontief, like the translog, provides a second-order approximation to an arbitrary functional form. The variabilities from the generalized Leontief model, reported in Appendix C, are lower overall than the corresponding translog variabilities. The translog model fits the data better than the generalized Leontief, as measured by R-squared. Since the various flexible functional forms would all be approximating the same underlying function, the Commission should not expect that use of an alternative functional form with the same approximation properties as the translog would alter the central result that mail processing labor variabilities are less than 100 percent.

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[31] The generalized Leontief functional form is $y=\sum_i \sum_j \gamma_{ij} \left(x_i x_j \right)^{1/2}$, $\gamma_{ij}=\gamma_{ji}$. See Robert G. Chambers, *Applied Production Analysis: A Dual Approach,* Cambridge, UK: Cambridge University Press, 1988, p. 181.

II.B.5. Issues pertaining to errors-in-variables

II.B.5.a. The TPF-FHP regressions from Docket No. R2000-1 imply high "reliability ratios" for automated and mechanized TPF and FHP, indicating that measurement error is not a significant problem for those cost pools

In section II.A.2, above, I demonstrated that the elasticities of TPF with respect to FHP, introduced by Dr. Neels in Docket No. R2000-1 as adjustment factors for the variabilities, are irrelevant to the measurement of volume-variable costs. However, the regressions (direct and reverse) involving TPF and FHP shed some light on the extent to which measurement error in the MODS workload measures may pose an econometric problem for the labor demand models and hence the variability estimates. In those regressions, a supposedly very noisy MODS workload measure and a handful of other variables manage to *explain nearly all of the variation in another supposedly very noisy MODS* workload measure, as measured by R-squared. Econometric theory indicates that the presence of random noise on both sides of the regression equation would depress the R-squared measure—the R-squared is lower, the greater the variance of the noise. In effect, it is not possible to explain nothing (the random noise) with something (the other variables). Therefore, the very high R-squared values from the TPF-FHP regressions suggest either that there is no material measurement error problems or that the errors in TPF and FHP are highly correlated. In Docket No. R2000-1, the Commission recognized this implication of the TPF-FHP regressions, but opined that too little was known about the processes generating errors in TPF and FHP to conclude that the error processes were independent (PRC Op., R2000-1, Vol. 2, App. F at 60).

For automated operations, the Commission's view is not consistent with the methods whereby TPF and FHP are measured. TPF and FHP are measured by independent methods for automated operations. The clear implication of this observation is that the errors are substantially independent, and the high R-squareds imply high statistical reliability of the MODS workload measures.

The TPF and FHP measurement processes for automated (and mechanized) operations are as follows. TPF (and TPH) data are obtained from machine counts of pieces inducted into the equipment. However, the machine counters cannot detect whether a particular handling represents the first distribution handling for any given piece, so the machine counts cannot be used to measure FHP. Accordingly, FHP measurements—in automated and manual operations alike—are made by weighing mail before it is sent to the first distribution operation, and converting the net weight to pieces using national conversion factors. While the conversion factors attempt to account for a variety of characteristics that would potentially affect the number of pieces per pound of mail (e.g., shape, machinability, class), there will generally be some degree of conversion error in FHP, resulting from the difference between the conversion factor and the actual pieces per pound for the individual batches of mail being weighed.

The independent procedures for TPF and FHP measurement strongly suggest that errors in TPF for automated and mechanized operations will be independent of errors in the corresponding FHP, whereas for manual operations, errors in TPH will not be independent of errors in FHP.

While little may be known about the causes of specific errors in the data, the factors that lead to errors in automated TPF are unlikely to be dependent on the factors leading to errors in automated FHP. In FHP measurement, the primary sources of errors include the conversion error (described above), scale malfunctions, and improper entry of container tare weights. There is no conversion, and hence no conversion error, in machine counts, nor would issues with the scales or the weighing process affect the machine counts of TPF taken from the sorting equipment. Likewise, faults in the machine counts will not affect the scale transactions.

In contrast, manual TPH are calculated as the sum of FHP and estimated subsequent handling pieces (SHP).[32] Since there is an explicit dependence of manual TPH on FHP, the conclusion that the errors in TPH and FHP are independent does not extend to manual operations.

At the "shapes level," the TPF-FHP analyses in Docket No. R2000-1 combined manual and automated operations (by shape). To eliminate the effect of the manual operations, I re-estimated the regressions from Docket No. R2000-1, LR-I-457, using only TPF and FHP from automated operations. For both letters and flats, adjusted R-squareds from the fixed effects models exceed 0.99

[32] See Docket No. R2000-1, USPS-T-15 at 50-52. The difference in methodology for automated and mechanized operations is designed to use exact piece counts where available. Machine counters can accurately count the total number of pieces inducted into the machine (TPF) and the number of pieces directed to reject bins (the difference between TPF and TPH), but cannot identify whether a handling represents the first distribution handling for the piece of mail (i.e., FHP). Therefore, automated and mechanized operations rely on weight conversions for FHP measurement. For manual operations, no practical source of exact piece counts for either FHP, SHP, or TPH exists.

in the direct and reverse regressions.[33] The success of the models in explaining the variation in TPF and FHP indicates that the contention that random measurement error materially affects automated TPF or FHP is very likely to be false. The results of the TPH-FHP analyses are appropriately interpreted as indicating high statistical reliability of TPF data for the cost pools representing automated and mechanized operations.

II.B.5.b. Available econometric guidance indicates that the 100 percent variability assumption significantly overstates manual variabilities

The dependence of manual TPH on FHP counts prevents the results from the automated and mechanized operations from being directly extended to manual operations. However, FHP in manual and automated operations are generated by common procedures. Thus, the results indicating that random measurement error is not a major problem for automated FHP also suggest that the statistical reliability of manual FHP data should also be relatively high.

Some results from econometric theory, though developed for simpler regression models than the recommended variability models, have been viewed by Dr. Neels (see Tr. 46-E/22318-22) as providing guidance as to the possible effect of measurement error on the variability estimates. One such result, contained in a *Handbook of Econometrics* chapter[34] used as a cross-examination

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[33] Even the pooled OLS models yield adjusted R-squareds in excess of 0.97. See LR-J-56, programs tpf-fhp-auto.tsp (direct regression) and tpf-fhp-auto-rev.tsp (reverse regression) for full results.

[34] Zvi Griliches, "Economic Data Issues." In Zvi Griliches and Michael D. Intriligator (eds.), *Handbook of Econometrics*, vol. 3 (Elsevier Science Publishers, 1986).

exhibit for Prof. Greene and Dr. Neels, suggests that the fixed effects and pooled OLS estimates would be biased in opposite directions in the presence of measurement error. If taken as guidance on the mail processing labor variabilities, this result suggests that the true variabilities would be bracketed by the fixed effects and OLS estimates.

The Commission's variabilities based on the 100 percent variability assumption are compared with the fixed effects and OLS estimates in Appendix A, Table A-1, below. By the guidance of the *Handbook of Econometrics* result, the 100 percent variability assumption fares poorly, as the Commission's variabilities fall outside the range bracketed by the fixed effects and OLS estimates for nine of the twelve cost pools under study, including all of the manual cost pools. The remaining three cost pools—BCS, OCR, and LSM—account for only 10 percent of the labor costs under study. The *Handbook* result would suggest that the Commission's application of the 100 percent variability assumption to the twelve cost pools studied here results in an overall upward bias of at least 13 percentage points.

One important result does not require generalization from simple models. To the extent that measurement error does not pose a significant estimation problem, as the evidence discussed above in Section II.B.5.a shows, then the range between the fixed effects and pooled OLS estimates will be dominated by the omitted variables bias in pooled OLS. In the absence of serious measurement error, there is no question that the fixed effects model provides the appropriate variability estimates.

II.B.6. Issues pertaining to the wage variable

The Commission criticized my wage variable as being a "plant level average" that may not be applicable to specific operations (PRC Op., R2000-1, Vol. 2, App. F at 51). The Commission's description of the wage variable as a plant level average was incorrect. The wages by Labor Distribution Code (LDC) that I used in Docket No. R2000-1 and continue to use in the current analysis are functional averages that represent a finer level of disaggregation than the plant level. In Docket No. R2000-1, I noted that:

> [M]ost of the important differences in compensation at the cost pool level (due to skill levels, pay grades, etc.) are related to the type of technology (manual, mechanized, or automated) and therefore are present in the LDC-level data. Thus, the LDC wage is a reasonable estimate of the cost pool-specific wage. (Docket No. R2000-1, USPS-T-15 at 92).

Table 1, below, shows the relationship between LDCs and cost pools, and the LDC wages applied to each cost pool for which I provide an estimated variability.

Table 1. Relationship between LDCs and cost pools

LDC (Wage variable)	LDC Description	Cost Pools included in LDC[35]	Variabilties using LDC wage
11 (WLDC11)	Automated letter distribution	BCS/ BCS/DBCS OCR	BCS/ BCS/DBCS OCR
12 (WLDC12)	Mechanized distribution—letters and flats (FSM/LSM)	FSM/ FSM/1000 LSM	FSM/ FSM/1000 LSM
13 (WLDC13)	Mechanized distribution—other than letters and flats	SPBS (Priority and Other) Mecparc 1SackS_m	SPBS
14 (WLDC14)	Manual distribution	MANF MANL MANP Manual Priority	MANF MANL MANP Manual Priority

The Commission also contended that since the LDC wage is calculated "by dividing wages by work hours," I employ a wage rate "that is correlated with the error in work hours, [the] dependent variable" (PRC Op., R2000-1, Vol. 2., App. F at 52) and therefore may contribute to simultaneity bias. The Commission's analysis is incorrect. First, the wage calculation actually divides LDC *dollars* by LDC work hours. Second, the Commission's analysis neglects the mathematically trivial yet crucial fact that the LDC dollars are the product of LDC work hours and the LDC wage rate. Therefore, work hours are present in

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[35] See LR-J-55, Section I.

both the numerator and denominator of the ratio and the division cancels out work hours, eliminating the supposed source of simultaneity bias. Thus, the wage variable does not raise significant estimation issues.

II.B.7. The Commission's interpretation of the capital elasticities is incorrect

The models I recommended in Docket No. R2000-1 yielded elasticities of cost pool workhours with respect to the facility capital index (capital elasticities) that were small, positive, and mostly statistically significant (Docket No. R2000-1, USPS-T-15 at 119-120). The Commission, interpreting these results as "capital productivities," argued that the capital elasticities implied massive waste of inputs. The Commission illustrated its claim with an example purporting to show how my models would predict an increase in labor costs, rather than labor savings, from deployment of the AFSM 100 (PRC Op., R2000-1, Vol. 2, App. F at 34-36). Consequently, the Commission viewed the capital elasticities as "plainly wrong," "incompatible with basic production theory," and evidence that the accompanying variabilities were "fatally flawed" (*id.* at 54-55).

The Commission's specific criticisms are mooted to some extent by the fact that the current results show capital elasticities that are still small but now mostly statistically insignificant and/or negative in sign (see Section IV.C.5, below). Nevertheless, the Commission's contention that the capital elasticities are nonsensical if they are positive is not correct. The flaw in the Commission's analysis is that it neglected the major source of cost savings from equipment deployment. Cost savings do not result from the deployment of the equipment *per se*, but rather from the transfer of processing (i.e., TPF) from lower-productivity to higher-productivity operations. The *ceteris paribus* effect of adding capital, which is measured by the capital elasticities, could be to increase costs slightly as, for instance, mailflows must be coordinated across more equipment. In this light, small positive capital elasticities need not be surprising, and do not imply that inputs are being "wasted" as long as the coordination-type costs are offset by the labor savings from shifting processing to the higher productivity operations. See also witness Kingsley's testimony, USPS-T-39, at 17-18.

The capital elasticities indicate the effect on labor costs of increasing capital input, other things equal. Significantly, TPF is among the "other things" held equal. To capture the full cost impact of an equipment deployment, it is necessary to determine the effect of the transfer of TPF across operations. The Commission made no effort to quantify the savings that would result from employing an expanded automation capacity, and therefore, its analysis was incomplete. The omission is significant, since when the capital elasticities are small, their effect on labor costs will be dwarfed by the effect of the shift of processing to higher-productivity operations.

The faulty conclusion drawn from the Commission's incomplete analysis can be readily shown using the AFSM example. The AFSM deployment, though representing a substantial national investment, would only increase the capital input for a mail processing plant modestly.[36] For the purpose of discussion,

[36] Most plants included in the first phase deployment were only scheduled to receive one AFSM machine.

assume the increase in facility capital input is 10 percent.[37] The capital elasticities from Docket No. R2000-1 implied that labor costs for the cost pools I studied would increase by $25 million,[38] other things equal. This is the labor (cost) increase to which the Commission refers. However, other things would *not* be equal, since the main purpose of the AFSM deployment is to shift processing from older, less productive FSMs to the much higher productivity AFSM operations.

The Commission's analysis completely ignored the labor savings from shifting processing from the older FSMs to the AFSMs. The omission is significant because AFSM productivity is double that of the older FSMs.[39] Suppose that the AFSM deployment were to allow half the FY 1998 FSM piece handlings to be shifted to the AFSM. Then, my BY 1998 FSM model would predict that the shift of processing from the older FSMs to the AFSM operation would reduce the volume-variable cost of the FSM operation by $426 million, i.e., half of the BY 1998 volume-variable cost in the FSM cost pool. Since the AFSM productivity is double that of the older FSMs, $213 million in volume-variable cost would be incurred in the AFSM operation to process the TPF shifted from the older FSMs. The net savings, including the $25 million effect from the capital

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[37] Because the AFSM deployment was still in progress as of FY 2000, I do not have actual data for the example in this section. The figure used in the example is illustrative, but intended to be realistic.

[38] To obtain this figure, I multiplied the FY 1998 cost pool dollars by the capital elasticities from pages 119-120 of USPS-T-15, summed the results, and multiplied by 0.1 (the 10 percent increase in facility capital).

[39] The factor-of-two increase in productivity from the FSM 881 to the AFSM 100 is consistent with both my observations of the AFSM in operation and AFSM productivity statistics communicated to me by witness Kingsley's staff.

elasticities, are $188 million, less any non-volume-variable costs of the AFSM operation. Far from indicating that the AFSM investment would be wasted, my models—correctly interpreted—predict a substantial labor savings.[40]

In general, the Postal Service's mail processing capital investments (and the related capital inputs) mainly bring about mail processing labor savings not by making existing operations more productive on the margin (or reducing costs other things equal), but rather by creating the capacity to shift workload (piece handlings) from lower productivity operations to higher productivity operations.

III. Changes to volume-variability methods for Mail Processing labor costs since R2000-1

III.A. Correction of computational errors identified by UPS witness Neels

In his response to Notice of Inquiry No. 4 in R2000-1, UPS witness Neels identified two computational errors affecting the Postal Service's recommended BY 1998 variabilities. Both errors have been corrected for the BY 2000 variabilities.

The errors in the BY 1998 calculations related to the application of a transformation to the regressors to adjust for the presence of autocorrelated regression disturbances in the recommended models. The first, and less serious, of the errors was the failure to transform the constant term along with the

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[40] In fact, the labor savings in this example are roughly comparable to the savings described by witness O'Tormey and cited by the Commission (at PRC Op., R2000-1, Vol. 2, App. F at 36).

other regressors. I correct the first error simply by transforming all of the regressors.[41]

The more serious error resulted from an interaction between the autocorrelation transformation and the algorithm that computes the panel data fixed effects estimator. The usual fixed effects algorithm computes the estimates by differencing the data from their facility means, which eliminates the facility fixed effects, and running an ordinary least squares regression (OLS) on the mean-differenced data to obtain unbiased estimates of the model coefficients. The coefficient estimates are unbiased (though statistically inefficient) regardless of the presence or absence of autocorrelation.

The autocorrelation adjustment is a two-stage procedure. In the first stage, the model is estimated using the mean differencing procedure without an adjustment. An estimated autocorrelation coefficient is calculated from the first stage regression and used to transform the data such that the transformed model does not exhibit autocorrelation. Then, in the second stage, the model is re-estimated using the transformed data, providing coefficient estimates that are unbiased and asymptotically efficient.

While the mean differencing procedure would be appropriate for a simple autocorrelation transformation, which would require omitting the first observation from every "run" of data in the second stage, I employed a more complicated transformation in order to be able to use more of the available observations in the second stage regressions. The error arose because, with the more complicated

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[41] In my recommended models, I specify dummy variables for all facilities in lieu of an overall constant.

transformation, the mean differencing procedure does not eliminate the facility fixed effects. Thus, while the first stage estimates were unbiased, the second stage coefficient estimates, which I used to compute my recommended variabilities, were biased. It should be noted that the cause of the bias is that my recommended results did *not* control for the facility-specific fixed effects.

I correct the second error for my recommended BY 2000 variabilities by employing a more computationally intensive procedure to compute the coefficient estimates for the fixed effects model. Specifically, I estimate the "dummy variables" formulation of the model rather than the mean differenced formulation. I specify a dummy variable for each facility and subject each dummy variable, along with the other regressors, to the autocorrelation transformation. The model is estimated using OLS, including the dummy variables, eliminating the need for mean differencing.[42] For comparison, I also estimate the models using the simpler autocorrelation transformation. Using the simpler alternative transformation does not materially change the results. See Appendix B.

III.B. Sample selection code derived from LR-I-239 programs

In responding to a UPS interrogatory in Docket No. R2000-1, I discovered that the computer code that implemented the sample selection procedures described in USPS-T-15 inadvertently excluded a small number of observations that otherwise passed the selection screens. I presented corrected code and

[42] The procedure is more computationally intensive because it greatly increases the maximum order of matrix inversion required by the regression procedure; it is also more memory intensive because the dummy variables are explicitly specified. Nevertheless, the calculations are well within the capabilities of the current generation of personal computers.

revised econometric results at Docket No. R2000-1, Tr. 15/6381-6 and LR-I-239. Since the number of observations affected was small, the effect of the error on the reported variabilities was trivial.[43] I base my current sample selection code on the corrected programs from LR-I-239.

III.C. More recent time period for regression sample

Since preparing my direct testimony in Docket No. R2000-1, FY 1999 and FY 2000 data have become available and have been incorporated into the mail processing volume-variability data set. The arrival of additional years' data can be used to (1) increase sample size by expanding the time dimension of the panel, (2) improve the currency of the sample by dropping earlier observations, or (3) some combination of the two.

Maximizing the size of the regression samples is not an object of an econometric analysis in itself. Adding time periods to a regression analysis using panel data involves a potential tradeoff between bias and variance of the regression coefficient estimators. If a common model applies to both the additional and "original" observations, then it is statistically more efficient to estimate the regression model using the combined sample. However, if the sets of observations have different data generating processes, or (more relevantly) if the differences in the data generating processes cannot be parameterized, then combining the observations is inappropriate in the sense that a regression using

[43] In fact, the error had the effect of a screen on a variable other than workhours (the dependent variable of the regression), in this case the coded site ID number. Therefore, it would not have biased the results regardless of the number of observations involved.

the combined observations will produce biased results. Serious problems also can arise from having too few time periods in the analysis. In the limiting case of one observation per site, cross-section analysis is subject to heterogeneity bias (a form of omitted variables bias) since it is unable to control for site-specific latent variables.

For my recommended BY 2000 volume-variability factors, I use the additional data to provide results based on a more recent data set than the BY 1998 analysis. Specifically, I drop the FY 1993 and FY 1994 observations from the sample used to estimate the recommended models. As a result, the maximum time series length per site in the regression samples, five years of quarterly observations, is approximately the same in both the BY 1998 and BY 2000 studies. Since the recommended model continues to employ the previous four quarters' TPF as explanatory variables, the earliest observations entering the regression sample date back to PQ1 of FY 1996.[44] The resulting sample sizes for the recommended BY 2000 variabilities are similar to those underlying my BY 1998 models.

III.D. Treatment of conversion factor change for manual letters and manual flats

In FY 1999, the Postal Service implemented changes to the conversion factors used in MODS to estimate letter and flat FHP from the weight of the mail and parcel FHP from container counts. Since manual TPH is based in part on

[44] FY 1995 is excluded from the regression sample period because one or more of the lagged TPF observations for an FY 1995 quarter would be from the excluded FY 1994 data. However, FY 1995 TPF data enter the regressions as lags to FY 1996 observations.

FHP, the conversion factor change affects the measurement of TPH in the manual letter, flat, parcel, and Priority Mail cost pools. The conversion factor change does not affect TPF and TPH measurement in automated and mechanized operations (BCS, FSM, LSM, OCR, and SPBS) because TPF and TPH in those operations are obtained from machine counts and are independent of FHP.[45]

I control for the TPH measurement change in the manual cost pools as follows. I define a dummy variable identifying the FY 1999 and FY 2000 time periods when the updated conversion factors are in effect. I then create interaction variables between the dummy variable and variables involving TPH (including higher-order and interaction terms, but not lagged TPH) and between the dummy variable and the manual ratio variable.[46] I add the new interaction variables to the estimating equation and modify the elasticity formulas appropriately. For full details, see the code for programs varltr-tph-by2000.tsp and varnl-tph-by2000.tsp in LR-J-56.

The effect of dropping the additional interaction variables that control for the conversion factor change is relatively small. Dropping the additional variables causes the manual letter, flat, and parcel variabilities to drop by small and statistically insignificant amounts; the manual Priority variability is unchanged. See Table 2, below. The relatively small effect likely results from the presence of both trend terms and interaction terms between the trend and other variables in the basic model specification. Since the function of those

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[45] See also Section II.B.5.a, above.

[46] The manual ratio variable is not included in the manual parcel and priority regression.

variables is to control for time-related autonomous factors, they may partly control for the change in measurement regime. In the future, the availability of one or two additional years of data under the current conversion factor regime will allow the pre-FY 1998 observations, and thus the controls for the change in measurement regime, to be dropped.

Table 2. Comparison of manual variabilities with and without controls for conversion factor change

Cost Pool	Variability, with controls for conversion factor change (recommended)	Variability, without controls for conversion factor change
Manual flats	71%	70%
Manual letters	58%	55%
Manual parcels	44%	43%
Manual Priority Mail	55%	55%

III.E. Elimination of manual ratio variable for automated letter and flat cost pools

The recommended BY 2000 models for automated and mechanized letter and flat sorting operations drop the "manual ratio" variables from their specifications. The "manual ratio" variables control for composition changes between manual and mechanized operations in the letter and flat mailstreams. The use of the "manual ratio" variables has been a source of controversies that arguably exceed the variables' role in the models. In Docket No. R97-1, the Commission rejected Prof. Bradley's models based in part on a finding that the manual ratio was volume-variable since it was a function of TPH. In Docket No. R2000-1, I mathematically derived the "manual ratio effect" and showed that it does not affect the degree of variability at the cost pool level.[47] I noted that whether a variable such as the manual ratio belonged in the model was an empirical issue of whether such cross-operation effects are relevant. However,

[47] Docket No. R2000-1, USPS-T-15, Appendix C. The "manual ratio effect" was also shown to exert a negligibly small effect on the distribution of volume-variable costs to subclass.

the Commission has suggested that the manual ratio may be "endogenous" and thus a source of simultaneity bias (PRC Op., R2000-1, Vol. 2, App. F at 69-70).

While updating the models, I revisited the issue of whether or not the inclusion of the manual ratio materially affected the variabilities. I considered automated/mechanized and manual operations separately, since the interconnections between them are asymmetric. Manual operations serve as "backstops" to automation to deal with machine rejects and machine capacity shortfalls, whereas automation operations by definition cannot provide reserve capacity for the processing of non-machinable mail. This suggests that the interconnections are likely to have a greater effect on manual operations as compared to automated operations.

I estimated the models for the letter and flat sorting cost pools with and without the manual ratio in the specification. The results for the automated and mechanized cost pools are presented in Table 3, below. The effect of excluding the manual ratio on the variabilities is less than one standard error for every cost pool, and thus not statistically significant. Since the more parsimonious specification produces statistically the same results as the more complicated model with the manual ratio, I recommend the manual ratio be excluded from those models.

The small effect on the results of excluding the manual ratio from the automated letter and flat operations has two implications of note. First, the result suggests that the theory that inclusion of the manual ratio variable leads to simultaneity bias is incorrect. To see this, suppose the manual ratio is a relevant explanatory variable. Then, excluding it from the specification just trades omitted variables bias for simultaneity bias. However, the mathematics of the omitted variables and simultaneity biases are very different, and there is no general reason to expect them to have the same direction or magnitude unless they are both zero.[48] Consequently, the small differences in Table 3 suggest that the manual ratio is not a source of either bias, and the Commission should not consider the remaining use of the manual ratio to lead to any significant econometric problems. Second, it calls into question Dr. Neels's contention that a tangle of interdependencies among operations effectively puts "correct" mail processing variability models out of reach (see Docket No. R2000-1, Tr. 15/12793-12795, 12843-12844 [UPS-T-1 at 21-23, 71-72]). The recommended labor demand models explain nearly all the variation in workhours in the automated and mechanized cost pools—96 percent or more, as measured by adjusted R-squared (see Tables 9-11, below)—without modeling interconnections among the cost pools. Put simply, if Dr. Neels's contention were correct, then it would not be possible to explain such a high percentage of the variation of the workhours without explicitly modeling the supposed interconnections. The interconnections among cost pools are either much less important than Dr. Neels suggests, or they contribute little independent variation relative to the other explanatory variables.

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[48] See Peter Schmidt, *Econometrics* (New York: Marcel Dekker, 1976) at 39-40 (omitted variables bias); 126-128 (simultaneous equations bias).

Table 3. Effect of dropping manual ratio variable from automated and mechanized letter and flat sorting operations.

Cost Pool	Variability, excluding manual ratio (recommended)	Variability, including manual ratio
BCS/	.94	.89
BCS/DBCS	.87	.88
FSM/	.74	.74
FSM/1000	.74	.74
LSM	.90	.95
OCR	.77	.78

The results for manual flats and letters are presented in Table 4. While manual flats are little affected by dropping the manual ratio, the manual letters variability drops sharply when the manual ratio is excluded. The difference is likely due to omitted variables bias in the model that excludes the manual ratio.[49] Accordingly, I continue to recommend that the manual ratio variables be included in the manual letters and flats models. As I demonstrated in Docket No. R2000-1, the volume effects transmitted through the manual ratio variable do not affect the degree of variability for a cost pool, so no adjustment to the manual variabilities is needed as a result of the presence of the manual ratio.

[49] As I indicated above, if simultaneity bias were the source of the difference, it would be unlikely that the differences for the automation cost pools would be statistically insignificant.

Table 4. Effect of dropping manual ratio variable from manual letter and flat sorting operations.

Cost Pool	Variability, including manual ratio (recommended)	Variability, excluding manual ratio
Manual Flats	71	72
Manual Letters	58	35

III.F. Disaggregation of BCS and FSM cost pools

The Postal Service's BY 2000 mail processing cost methodology disaggregates the BCS and FSM cost pools based on equipment types (see also USPS-T-13 at 4). The disaggregation splits the BCS cost pool into DBCS and other BCS operations (the latter mainly comprising MPBCS operations). The FSM cost pool is split into FSM 1000 and other FSM operations. I estimate variabilities corresponding to each of the disaggregated cost pools. For comparison purposes, I also estimate variabilities for the aggregate BCS and FSM cost pools employed in the Docket No. R97-1 and Docket No. R2000-1 studies, using the BY 2000 methodology. The aggregated and disaggregated variabilities for the BCS and FSM cost pools are presented in Table 5, below.

As discussed in Section II.B.3, above, the correct interpretation of differences between disaggregated and aggregated variabilities is that the aggregated approach is inappropriate. The Table 5 results indicate that aggregation is somewhat less problematic for the BCS cost pool than for the FSM cost pool. The combined FSM pool has undergone a large composition shift in the sample period related to the introduction of the FSM 1000; the FSM

1000 share of total FSM workhours was near zero in FY 1996 (Docket No. R97-1, LR-H-146 at I-14) and nearly 30 percent in FY 2000. FSM 1000 productivity is lower than FSM 881 productivity,[50] so the composition change would tend do lower the average productivity of the combined FSM group. Without controls for the composition change, the aggregate analysis may misread the average productivity decline as a higher degree of volume-variability.

Table 5. Comparison of aggregated and disaggregated variabilities for BCS and FSM operations.

Cost Pool	BY 2000 disaggregated variability	Aggregated variability
BCS/	94%	93%
BCS/DBCS	87%	
FSM/	74%	84%
FSM/1000	74%	

III.G. Evaluation of volume-variability factors using FY 2000 observations

The volume-variability factors derived from the mail processing labor demand models are functions of certain regression coefficients and explanatory variables. Consequently, the point estimates of the volume-variability factors depend on the estimated regression coefficients and the particular values of the explanatory variables used to evaluate the variability functions.

In Docket No. R2000-1, I reviewed several approaches to evaluate the variability functions that had been proposed in previous rate proceedings. The

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[50] Note that the FSM 1000 was designed to substitute for manual processing of flats that are not machinable on the FSM 881. FSM 1000 productivity is higher than manual flat sorting productivity

common thread was that all of the methods sought to employ representative values of the explanatory variables. However, they differed in the specific method used to arrive at the representative values—e.g., arithmetic versus geometric means, weighted versus unweighted averages. I concluded that the arithmetic mean method employed by Prof. Bradley in Docket No. R97-1, in which the variability functions were evaluated at the arithmetic mean values for the full regression sample, was justifiable and did not produce results markedly different than the alternatives. I thus recommended the continued use of Prof. Bradley's arithmetic mean method for the BY 1998 study. See Docket No. R2000-1, USPS-T-15 at 72-79.

My recommended BY 2000 variabilities modify the previous approach by using the arithmetic means of only the FY 2000 observations to evaluate the elasticity functions. This approach is intended to ensure that the values of the explanatory variables used to evaluate the elasticity functions for the Postal Service's BY 2000 CRA are representative of Base Year conditions. The two methods are compared in Table 6, below. The overall effect of the change is small.

Table 6. Comparison of variabilities evaluated at FY 2000 and overall mean

Cost Pool	BY 2000 recommended variabilities (evaluated at means of FY 2000 observations)	Alternative variabilities (evaluated using means of all observations in regression sample)
BCS/	0.94	0.86
BCS/DBCS	0.87	0.89
FSM	0.74	0.73
FSM/1000	0.74	0.74
OCR	0.77	0.69
LSM	0.90	0.93
Manual Flats	0.71	0.68
Manual Letters	0.58	0.60
Manual Parcels	0.44	0.46
Manual Priority	0.55	0.51
SPBS	0.66	0.65
Composite	0.71	0.70

III.H. Threshold screen on TPF (or TPH)

Prof. Greene's review of my sample selection procedures in Docket No. R2000-1 raised the possibility that the threshold screen, which omitted from the regression samples a relatively small number of observations with workhours too low to represent normal plant operations,[51] could have imparted a selection bias on the results (Tr. 46-E/22051). Prof. Greene noted that screens on the explanatory variables do not result in a bias (id.).

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[51] The screen on workhours had been intended to address the issue that Prof. Bradley's TPH-based threshold screen was potentially too restrictive for lower productivity operations. See Docket No. R2000-1, USPS-T-15 at 108-109.

To eliminate the possibility of introducing a bias through the threshold screen, I employ a threshold screen on the TPF variable (TPH for manual operations) rather than the workhours variable. The TPF threshold for each cost pool is the TPF that would result from 40 hours of operation at the high productivity cutoff value used in the productivity screen. This method has the desirable characteristic that the threshold representing normal operations is set higher in high productivity operations than low productivity operations. Accordingly, it addresses the Docket No. R97-1 concerns that Dr. Bradley's original threshold screen on TPH was potentially too restrictive for lower productivity operations (see Docket No. R2000-1, USPS-T-15 at 108-109). As was noted in Docket No. R2000-1, a level of TPF that may represent normal operations in a relatively low productivity activity, such as manual letter sorting, may not represent normal operations in high productivity activities such as BCS sorting (*id.* at 96-97).

IV. Principal results of the volume-variability analysis for mail processing labor costs

The mail processing volume-variability analysis uses the three distinct estimating equations. First, the automated and mechanized operations—BCS (non-DBCS), DBCS, FSM (881), FSM/1000, LSM, OCR, and SPBS—employ the following estimating equation (15):

$$
\begin{aligned}
\ln HRS_{int} = {} & \textstyle\sum_{k=1}^{N} \beta_{1k} SITEk_n \\
& +(\alpha_1 + \gamma_1 L + \gamma_2 L^2 + \gamma_3 L^3 + \gamma_4 L^4)\ln TPF_{int} \\
& +(\alpha_{11} + \gamma_{11} L + \gamma_{22} L^2 + \gamma_{33} L^3 + \gamma_{44} L^4)(\ln TPF_{int})^2 \\
& +\alpha_2 \ln CAP_{nt} + \alpha_{22}(\ln CAP_{nt})^2 + \alpha_3 \ln DEL_{nt} + \alpha_{22}(\ln DEL_{nt})^2 \\
& +\alpha_4 \ln WAGE_{int} + \alpha_{22}(\ln WAGE_{int})^2 + \alpha_5 TREND_t + \alpha_{55} TREND_t^2 \\
& +\alpha_{12} \ln TPF_{int} \ln CAP_{nt} + \alpha_{13} \ln TPF_{int} \ln DEL_{nt} + \alpha_{14} \ln TPF_{int} \ln WAGE_{int} \\
& +\alpha_{15} \ln TPF_{int} \cdot TREND_t \\
& +\alpha_{23} \ln CAP_{nt} \ln DEL_{nt} + \alpha_{24} \ln CAP_{nt} \ln WAGE_{int} + \alpha_{25} \ln CAP_{nt} \cdot TREND_t \\
& +\alpha_{34} \ln DEL_{nt} \ln WAGE_{int} + \alpha_{35} \ln DEL_{nt} \cdot TREND_t \\
& +\alpha_{45} \ln WAGE_{int} \cdot TREND_t \\
& +\beta_2 QTR2_t + \beta_3 QTR3_t + \beta_4 QTR4_t \\
& +\varepsilon_{int}
\end{aligned}
\tag{15}
$$

where the subscripts *i, n* and *t* refer to the cost pool, site, and time period, respectively; *L* denotes the lag operator.[52] The variables are:

TPF: Total Pieces Fed for cost pool *i*, site *n*, and time *t*,

CAP: Facility capital input index for site *n*, and time *t*,

DEL: Possible deliveries (sum of city, rural, highway contract, and P. O. box) for site *n*, and time *t*,

WAGE: Wage (compensation per workhour) for the LDC associated with cost pool *i* (see Table 1, above), site *n*, and time *t*,

[52] The lag operator is defined such that $L^s x_t = x_{t-s}$.

TREND: Time trend, set to 1 for Postal Quarter (PQ) 1, FY 1993, incremented linearly by PQ for time *t*,

SITE*X*: Dummy variable, equals 1 if for observations of site *X*, zero otherwise; used to implement fixed effects model,[53] and

QTR*X*: Dummy variable, equals 1 if time *t* corresponds to PQ *X*, zero otherwise.[54]

No *a priori* constraints are placed on the coefficients. Among other things, this allows the effects of facility-level variables to vary by operation.

Second, the specification for the manual cost pools—flats, letters, parcels, and Priority Mail—is more complicated because of the controls for the change in conversion factor regime. These specifications include interaction terms between manual TPH and variables involving manual TPH, including the manual ratio for manual letters and manual flats, and a dummy variable indicating the FY 1999 and FY 2000 time periods in which the new conversion factors are in effect. The estimating equation for manual letters and manual flats is equation (16):

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[53] Dummy variables for all sites are included in the regression, so the overall constant term is omitted to avoid multicollinearity.

[54] QTR1 is omitted to avoid multicollinearity.

$$
\begin{aligned}
\ln HRS_{int} = & \sum_{k=1}^{N} \beta_{1k} SITEk_n \\
& +(\alpha_1 + \lambda_1 CONV_t + \gamma_1 L + \gamma_2 L^2 + \gamma_3 L^3 + \gamma_4 L^4) \ln TPH_{int} \\
& +(\alpha_{11} + \lambda_{11} CONV_t + \gamma_{11} L + \gamma_{22} L^2 + \gamma_{33} L^3 + \gamma_{44} L^4)(\ln TPH_{int})^2 \\
& +\alpha_2 \ln CAP_{nt} + \alpha_{22}(\ln CAP_{nt})^2 + \alpha_3 \ln DEL_{nt} + \alpha_{22}(\ln DEL_{nt})^2 \\
& +\alpha_4 \ln WAGE_{int} + \alpha_{22}(\ln WAGE_{int})^2 + \alpha_5 TREND_t + \alpha_{55} TREND_t^2 \\
& +(\alpha_6 + \lambda_6 CONV_t) \ln MANR_{int} + (\alpha_{66} + \lambda_{66} CONV_t)(\ln MANR_{int})^2 \\
& +(\alpha_{12} + \lambda_{12} CONV_t) \ln TPH_{int} \ln CAP_{nt} + (\alpha_{13} + \lambda_{13} CONV_t) \ln TPH_{int} \ln DEL_{nt} \\
& +(\alpha_{14} + \lambda_{14} CONV_t) \ln TPH_{int} \ln WAGE_{int} + (\alpha_{15} + \lambda_{15} CONV_t) \ln TPH_{int} \cdot TREND_t \\
& +(\alpha_{16} + \lambda_{16} CONV_t) \ln TPH_{int} \ln MANR_{int} \\
& +\alpha_{23} \ln CAP_{nt} \ln DEL_{nt} + \alpha_{24} \ln CAP_{nt} \ln WAGE_{int} + \alpha_{25} \ln CAP_{int} \cdot TREND_t \\
& +(\alpha_{26} + \lambda_{26} CONV_t) \ln CAP_{nt} \ln MANR_{int} \\
& +\alpha_{34} \ln DEL_{nt} \ln WAGE_{int} + \alpha_{35} \ln DEL_{nt} \cdot TREND_t \\
& +(\alpha_{36} + \lambda_{36} CONV_t) \ln DEL_{nt} \ln MANR_{int} \\
& +\alpha_{45} \ln WAGE_{int} \cdot TREND_t + (\alpha_{46} + \lambda_{46} CONV_t) \ln WAGE_{int} \ln MANR_{int} \\
& +(\alpha_{56} + \lambda_{56} CONV_t) TREND_t \ln MANR_{int} \\
& +\beta_2 QTR2_t + \beta_3 QTR3_t + \beta_4 QTR4_t \\
& +\varepsilon_{int}. \qquad (16)
\end{aligned}
$$

with the additional variables

MANR: manual TPH as a percentage of total TPH, for the appropriate shape, and

CONV: A dummy variable indicating periods using new MODS conversion factors, equals 1 for time periods *t* in FY 1999 and FY 2000, zero otherwise.

Other variable definitions are as above.

Finally, the estimating equation for the manual parcels and manual Priority Mail cost pools excludes the manual ratio variable, and is given by equation (17):

$$
\begin{aligned}
\ln HRS_{int} = {} & \sum_{k=1}^{N} \beta_{1k} SITEk_n \\
& +(\alpha_1 + \lambda_1 CONV_t + \gamma_1 L + \gamma_2 L^2 + \gamma_3 L^3 + \gamma_4 L^4)\ln TPH_{int} \\
& +(\alpha_{11} + \lambda_{11} CONV_t + \gamma_{11} L + \gamma_{22} L^2 + \gamma_{33} L^3 + \gamma_{44} L^4)(\ln TPH_{int})^2 \\
& +\alpha_2 \ln CAP_{nt} + \alpha_{22}(\ln CAP_{nt})^2 + \alpha_3 \ln DEL_{nt} + \alpha_{22}(\ln DEL_{nt})^2 \\
& +\alpha_4 \ln WAGE_{int} + \alpha_{22}(\ln WAGE_{int})^2 + \alpha_5 TREND_t + \alpha_{55} TREND_t^2 \\
& +(\alpha_{12} + \lambda_{12} CONV_t)\ln TPH_{int} \ln CAP_{nt} + (\alpha_{13} + \lambda_{13} CONV_t)\ln TPH_{int} \ln DEL_{nt} \\
& +(\alpha_{14} + \lambda_{14} CONV_t)\ln TPH_{int} \ln WAGE_{int} + (\alpha_{15} + \lambda_{15} CONV_t)\ln TPH_{int} \cdot TREND_t \\
& +\alpha_{23} \ln CAP_{nt} \ln DEL_{nt} + \alpha_{24} \ln CAP_{nt} \ln WAGE_{int} + \alpha_{25} \ln CAP_{int} \cdot TREND_t \\
& +\alpha_{34} \ln DEL_{nt} \ln WAGE_{int} + \alpha_{35} \ln DEL_{nt} \cdot TREND_t \\
& +\alpha_{45} \ln WAGE_{int} \cdot TREND_t \\
& +\beta_2 QTR2_t + \beta_3 QTR3_t + \beta_4 QTR4_t \\
& +\varepsilon_{int}. \qquad (17)
\end{aligned}
$$

For all of the cost pools, the regression error ε_{int} is allowed to exhibit first-order serial correlation. As was the case in the BY 1998 study, the GLS procedure is a version of the "Baltagi-Li" autocorrelation adjustment (see Docket No. R97–1, USPS–T–14, at 50) modified to accommodate breaks in sites' regression samples (see also section III.A). The standard errors reported in Tables 7, 8, and 9 are computed using a heteroskedasticity-consistent covariance matrix for the regression coefficients.

IV.A. Summary statistics for the regression samples

Table 7. Summary of effect of sample selection rules on sample size

Cost Pool	Non-missing	Threshold	Productivity	Minimum Obs	Lag Length (Regression N)
BCS	6173	6035	5803 94.0%	5446	4327 70.0%
BCS/DBCS	6575	6569	6342 96.5%	6117	4893 71.8%
FSM	5595	5595	5573 99.6%	5531	4542 81.2%
FSM/1000	2388	2386	2283 95.6%	1488	1056 44.2%
OCR	6488	6465	6295 97.0%	6018	4788 73.8%
SPBS	3318	3300	3266 98.4%	2869	2295 69.2%
LSM	3233	3210	3197 98.9%	1695	1213 37.5%
MANF	6876	6863	6438 93.6%	6159	4849 70.5%
MANL	6888	6886	6732 97.7%	6530	5284 76.7%
MANP	5573	5448	4313 77.4%	3575	2741 49.2%
Manual Priority	5555	5345	4707 84.7%	4006	3044 54.8%

Percentages are of non-missing observations.

Table 8. Selected summary statistics for regression samples

Cost Pool	Median Hours	Median TPF (000)	Median wage ($/hr)	Median productivity (TPF/hr), "unscrubbed" data
BCS/	8278	57567	25.05	7188
BCS/DBCS	13899	111333	25.20	8281
OCR	5560	32522	25.12	6698
FSM/	18412	12619	28.87	711
FSM/1000	16045	8843	28.76	604
LSM	10182	13096	29.08	1329
MANF	8337	4372	25.15	523
MANL	25462	14574	25.17	584
MANP	1559	372	25.44	313
Manual Priority	3647	757	24.89	231
SPBS	19685	4789	25.91	259

IV.B. Recommended volume-variability factors and other econometric results

Principal econometric results for my recommended models are presented in Tables 9, 10, and 11, below. I produced the results with TSP version 4.4 econometric software, running on a personal computer with an AMD Athlon processor, 256 MB RAM, and the Windows 2000 operating system. I also replicated the results of the TSP programs using SAS. The TSP and SAS code, along with the complete output files, are included in LR-J-56.

1 **Table 9. Principal results for letter sorting operations, USPS Base Year**
2 **method**

Cost Pool	BCS/ DBCS	BCS/	OCR	LSM	Manual Letters
Output Elasticity or Volume-Variability Factor	0.87 (0.05)	0.94 (0.05)	0.77 (0.06)	0.90 (0.06)	0.58 (0.04)
Wage Elasticity	-0.91 (0.10)	-0.95 (0.15)	-0.71 (0.14)	-0.34 (0.25)	-0.85 (0.06)
Deliveries Elasticity	-0.14 (0.21)	-0.40 (0.42)	-0.78 (0.26)	-2.52 (0.94)	0.03 (0.19)
Capital Elasticity	0.03 (0.02)	-0.07 (0.05)	-0.00 (0.03)	-0.06 (0.09)	0.00 (0.02)
Manual Ratio Elasticity	N/A	N/A	N/A	N/A	-1.83 (0.81)
Auto-correlation coefficient	0.679	0.688	0.699	0.428	0.672
Adjusted R-squared	0.983	0.962	0.967	0.985	0.991
N observations	4893	4327	4788	1213	5284

Elasticities evaluated using arithmetic mean method. Heteroskedasticity-consistent standard errors in parentheses.

Table 10. Principal results for flat sorting operations, USPS Base Year method

Cost Pool	FSM/	FSM/1000	Manual Flats
Output Elasticity or Volume-Variability Factor	0.74 (0.05)	0.74 (0.05)	0.71 (0.05)
Wage Elasticity	-0.56 (0.07)	-0.59 (0.14)	-0.18 (0.11)
Deliveries Elasticity	0.23 (0.18)	-0.01 (0.41)	0.64 (0.29)
Capital Elasticity	0.02 (0.02)	0.05 (0.05)	-0.04 (0.03)
Manual Ratio Elasticity	N/A	N/A	-0.65 (0.63)
Auto-correlation coefficient	0.671	0.467	0.640
Adjusted R-squared	0.991	0.985	0.984
N observations	4542	1056	4849

Elasticities evaluated using arithmetic mean method. Heteroskedasticity-consistent standard errors in parentheses.

Table 11. Principal results for other operations with piece handling data, USPS Base Year method

Cost Pool	Manual Parcels	Manual Priority	SPBS
Output Elasticity or Volume-Variability Factor	0.44 (0.04)	0.55 (0.05)	0.66 (0.05)
Wage Elasticity	-0.71 (0.22)	-1.77 (0.24)	-1.18 (0.21)
Deliveries Elasticity	-0.78 (0.60)	0.63 (0.90)	-0.60 (0.37)
Capital Elasticity	0.00 (0.06)	0.10 (0.06)	0.01 (0.03)
Autocorrelation coefficient	0.559	0.498	0.666
Adjusted R-squared	0.924	0.934	0.983
N observations	2741	3044	2295

Elasticities evaluated using arithmetic mean method. Heteroskedasticity-consistent standard errors in parentheses.

IV.C. Discussion of results

IV.C.1. Specification tests favor the fixed effects model and the translog functional form

The recommendation of results from the fixed effects model does not reflect an *a priori* preference, but rather is consistent with specification tests that decisively reject the simpler "pooled" OLS model (with a common intercept for all sites) in favor of the fixed effects specification. Consistent with the results of similar tests in Docket No. R97-1 and in Docket No. R2000-1, the F-tests of the fixed effects specification versus the pooled OLS specification strongly favor fixed effects. Table 12, below, presents the test statistics and p-values.

Table 12. F-statistics for tests of fixed effects versus pooled OLS specifications

Cost pool	F-statistic, fixed effects versus pooled OLS	*P*-value	Reject pooled OLS?
BCS/	6.09	<0.00005	Yes
BCS/DBCS	30.85	<0.00005	Yes
FSM/	8.32	<0.00005	Yes
FSM/1000	5.96	<0.00005	Yes
OCR	6.25	<0.00005	Yes
LSM	7.02	<0.00005	Yes
Manual Flats	8.22	<0.00005	Yes
Manual Letters	11.76	<0.00005	Yes
Manual Parcels	12.40	<0.00005	Yes
Manual Priority	7.02	<0.00005	Yes
SPBS	9.37	<0.00005	Yes

In response to the specification issues discussed in Section II.B.4, above, I also tested the translog specification against the simpler log-linear specification.[55] The log-linear functional form is obtained from the translog by restricting the coefficients on second-order and interaction terms to zero. I used the standard F-test statistic for a set of zero restrictions on linear regression coefficients. In every case, the more restrictive log-linear specification is decisively rejected in favor of the translog, with p-values of zero to at least four decimal places. The test results are presented in Table 13, below.

[55] In Docket No. R2000-1, I did not present formal test results, but the presence of statistically significant coefficients on second-order and interaction terms in the detailed results strongly suggested that the log-linear functional form would have been rejected in favor of the translog.

Table 13. F-statistics for tests of translog versus log-linear functional forms.

Cost pool	F-statistic	Numerator degrees of freedom (d.f.)	Denominator d.f.	*P*-value	Reject log-linear?
BCS/	7.20	18	4057	<0.00005	Yes
BCS/DBCS	7.31	18	4588	<0.00005	Yes
FSM/	22.12	18	4277	<0.00005	Yes
FSM/1000	3.80	18	918	<0.00005	Yes
OCR	9.31	18	4493	<0.00005	Yes
LSM	8.92	18	1068	<0.00005	Yes
Manual Flats	7.14	35	4529	<0.00005	Yes
Manual Letters	13.33	35	4955	<0.00005	Yes
Manual Parcels	3.85	23	2541	<0.00005	Yes
Manual Priority	4.70	23	2814	<0.00005	Yes
SPBS	10.96	18	2126	<0.00005	Yes

IV.C.2 Comparison to Docket No. R2000-1 variabilities

Direct comparison of the recommended BY 2000 mail processing variabilities with the BY 1998 variabilities I recommended in Docket No. R2000-1 is not appropriate, primarily because the previous results were affected by the technical errors that have been corrected for BY 2000 (see Section III.A, above). However, as I explained above, results from models that did not employ an autocorrelation adjustment would not be affected by the technical errors and would not be biased by the absence of an autocorrelation adjustment. In Docket No. R2000-1, variabilities without the autocorrelation adjustment were presented in LR-I-239. The unadjusted (for autocorrelation) variabilities from LR-I-239, and the BY 2000 recommended variabilities are presented in Table 14, below.

The BY 1998 variabilities are lower, overall, than the recommended BY 2000 variabilities. The most pronounced differences at the cost pool level are in the flat sorting operations. These differences may represent the results of changes in flat sorting operations related to the deployment of the FSM 1000.

Table 14. Comparison of BY 2000 and BY 1998 variabilities

Cost Pool	BY 1998 Variability, without autocorrelation adjustment (@ FY 1998 mean), from LR-I-239	BY 2000 Variability (@ FY 2000 mean)
BCS/[56]	0.88	0.94
BCS/DBCS	N/A	0.87
FSM/[57]	0.65	0.74
FSM/1000	N/A	0.74
OCR	0.79	0.77
LSM	0.97	0.90
Manual Flats	0.56	0.71
Manual Letters	0.60	0.58
Manual Parcels	0.43	0.44
Manual Priority	0.51	0.55
SPBS	0.65	0.66
Composite	0.67	0.71

[56] The BY 1998 BCS/ elasticities are for the combined BCS operation group.

[57] The BY 1998 FSM/ elasticities are for the combined FSM operation group.

IV.C.3. Implications for productivities

The Commission described the estimated elasticities as having the "surprising" implication that "labor costs would quickly approach zero as volume increases" (PRC Op., R2000-1, Vol. 2, App. F at 34). The variabilities do imply that marginal labor productivities are higher than average productivities, which in turn implies that average costs locally decrease with small increases in TPF, other things equal. In order for average costs to vanish, though, the Commission must assume a constant degree of volume-variability over an infinite increase in TPF. Such an assumption is unwarranted for two principal reasons. First, the mail processing variabilities are not constants, but rather are functions of the variables that appear in the labor demand (and cost functions).[58] Second, the Commission's constant variability extrapolation is inappropriate because it neglects the fact that human and machine capabilities will place nonzero floors on marginal costs. A more reasonable alternative extrapolation, such as assuming constant marginal cost (or, equivalently, marginal productivity—the ratio of the average productivity to the volume-variability factor) need not violate the marginal cost floors. In this light, the most obvious flaw is not in the results of the variability analysis but rather in the Commission's faulty extrapolation of the econometric results. From the foregoing discussion, a more trenchant criticism would arise if the marginal productivities exceeded human or machine capabilities.

[58] The special cases that would yield constant variabilities, such as log-linear labor demand functions, have been shown not to hold for mail processing operations (cf. Table 13, above).

The marginal productivities are, in fact, feasible, and actually help explain some features of the average productivity data. As witness Kingsley notes, sorting a letter at a case only takes 2-4 seconds, but the average time per piece in manual letters is six seconds (the average productivity is approximately 600 pieces per hour). The 58 percent variability, though seemingly very low, implies that the marginal time to sort a letter manually is some 3.5 seconds,[59] which reconciles witness Kingsley's observation with the average productivity data.

IV.C.4 Wage elasticities

Economic theory predicts that labor demand should vary inversely with the wage rate. The elasticities of workhours with respect to the LDC wage show that mail processing labor demand behaves as expected by theory—the wage elasticities are negative, statistically significant, and generally less than unity.

IV.C.5. Capital elasticities

In Docket No. R2000-1, the Commission found the result that the capital elasticities were (generally) small, positive, and statistically significant to be an indication that the variability models were "fatally flawed" (PRC Op. R2000-1, Appendix F at 34-36, 54-55). I explained in Section II.B.7, above, that the Commission's economic conclusions were not warranted. The current results, in contrast to the results from Docket No. R2000-1, show the capital elasticities are small, mostly statistically insignificant, and often negative in sign. The small

[59] The 600 piece per hour average productivity and 58 percent variability imply a marginal productivity of 1,035 pieces per hour, or 3.5 seconds per piece.

magnitudes of the capital elasticities are consistent with the observation that the main way in which capital affects labor input is by providing productive capacity in higher productivity (automated) operations, rather than by making specific (existing) mail processing operations more productive.

The Commission has suggested that the facility-level capital index used in the recommended models may not be appropriate for application to specific cost pools (PRC Op., R2000-1, Vol. 2, App. F at 46). Developing cost pool-specific capital input indexes would be a substantial undertaking, so given the amount of time that has elapsed since the end of Docket No. R2000-1, I have not been able to test the sensitivity of the full set of variabilities to the specification of alternative capital measures. However, from the existing analysis from which the facility-level capital index is developed, I was able to obtain a sub-index (variable name QIAHE) for automated letter sorting equipment (BCS and OCR). I re-estimated the BCS and OCR variabilities using QIAHE in lieu of the facility capital index (QICAP) and found that neither the variabilities nor the capital elasticities were materially affected by the substitution; see Appendix D for results.

IV.C.6. Deliveries and network effects

The elasticities of workhours with respect to possible deliveries ("deliveries elasticities") derived from the recommended models suggest that network effects are harder to accurately quantify than the (uncorrected) BY 1998 results indicated. The BY 2000 deliveries elasticities from the fixed effects models exhibit widely varying point estimates (across cost pools) in sign and magnitude, combined with relatively large standard errors. In contrast, the deliveries elasticities for the pooled OLS model, reported in Appendix A, Table A-2, are statistically well-behaved. The result that the inclusion of the site dummy variables dramatically inflates the standard errors of the deliveries elasticities is classically symptomatic of near-multicollinearity between possible deliveries and the fixed effects. The implied high correlation between the possible deliveries and the fixed effects reinforces the argument that the fixed effects represent the effect of non-volume factors such as fixed network characteristics. Whether the model specifications can be modified to quantify the effects of the network on mail processing labor cost with low standard errors is a matter for future research.

Appendix A. Results from estimation of the labor demand models by pooled OLS

Table A–1. Cost pool and composite variabilities from pooled OLS estimation, compared to fixed effects model and Commission methodology

Cost Pool	Variability, fixed effects (USPS BY 2000)	Variability, pooled OLS (rejected by F-tests)	Variability, Commission methodology	Commission variability in FE-OLS range?
BCS	0.94	1.04	1.00	Yes
BCS/DBCS	0.87	0.91	1.00	No
FSM	0.74	0.95	1.00	No
FSM/1000	0.74	0.75	1.00	No
OCR	0.77	1.04	1.00	Yes
LSM	0.90	0.88	0.99	No
Manual Flats	0.71	0.91	1.00	No
Manual Letters	0.58	0.83	1.00	No
Manual Parcels	0.44	0.58	0.99	No
Manual Priority	0.55	0.70	0.99	No
SPBS	0.66	0.82	0.99	No
Composite Variability	0.71	0.87	1.00	No

Table A–2. Deliveries elasticities from pooled OLS estimation, compared to fixed effects model

Cost Pool	Deliveries elasticites, fixed effects model	Deliveries elasticities, pooled OLS
BCS	-0.14 (0.21)	0.20 (0.07)
BCS/DBCS	-0.40 (0.42)	0.16 (0.05)
FSM	0.23 (0.18)	0.16 (0.04)
FSM/1000	-0.01 (0.41)	0.17 (0.06)
OCR	-0.78 (0.26)	-0.01 (0.07)
LSM	-2.52 (0.94)	0.04 (0.10)
Manual Flats	0.64 (0.29)	0.26 (0.05)
Manual Letters	0.03 (0.19)	0.28 (0.04)
Manual Parcels	-0.78 (0.60)	0.43 (0.08)
Manual Priority	0.63 (0.90)	0.24 (0.08)
SPBS	-0.60 (0.37)	0.12 (0.06)

Standard errors in parentheses.

Appendix B. Results based on alternative autocorrelation adjustments

Table B–1. Volume-variability factors from recommended autocorrelation adjustment, alternative adjustment, and no adjustment

Cost Pool	Recommended model	Alternative adjustment	No adjustment
BCS	0.94	0.90	0.91
BCS/DBCS	0.87	0.84	0.94
FSM	0.74	0.74	0.71
FSM/1000	0.74	0.72	0.74
OCR	0.77	0.75	0.83
LSM	0.90	0.92	0.90
Manual Flats	0.71	0.67	0.61
Manual Letters	0.58	0.56	0.54
Manual Parcels	0.44	0.41	0.47
Manual Priority	0.55	0.60	0.55
SPBS	0.66	0.62	0.69
Composite Variability	0.71	0.69	0.70

Appendix C. Results from generalized Leontief functional form

Table C–1. Selected results from generalized Leontief model

Cost Pool	BCS/	BCS/DBCS	FSM/	FSM/1000	OCR
Output Elasticity (Volume-variability factor)	0.77 (0.05)	0.83 (0.05)	0.66 (0.06)	0.68 (0.04)	0.63 (0.06)
Wage Elasticity	-1.29 (0.15)	-1.13 (0.11)	-0.56 (0.05)	-0.53 (0.11)	-0.92 (0.14)
Adjusted R-squared	0.775	0.866	0.921	0.884	0.751
N observations	4327	4893	4542	1056	4788

Standard errors in parentheses.

Appendix D. Results from alternative capital index for letter automation operations

Table D–1. Variabilities and other selected results from specification of alternative letter automation capital index

Cost Pool	BCS/	BCS/ DBCS	OCR	Combined BCS
Output Elasticity (Volume-variability factor)	0.91 (0.05)	0.87 (0.05)	0.71 (0.05)	0.89 (0.06)
Deliveries Elasticity	-0.44 (0.42)	-0.23 (0.20)	-0.86 (0.28)	-0.17 (0.20)
Wage Elasticity	-0.93 (0.15)	-0.93 (0.09)	-0.66 (0.14)	-0.83 (0.08)
Capital Elasticity	-0.10 (0.06)	0.02 (0.03)	0.01 (0.05)	-0.04 (0.04)
Adjusted R-squared	0.963	0.983	0.967	0.985
N observations	4327	4889	4788	5441

Standard errors in parentheses.