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Relative prices and electronic substitution: Changes in household-level demand for postal delivery services from 1986 to 2004

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ABSTRACT

This paper quantifies the extent to which the shift in the aggregate household-level demand for postal delivery services can be attributed to the appearance of alternative modes of communication versus the concomitant rise in postal prices. We find that both recent postal price increases and the penetration of personal computer technology among US households led to similar reductions in postal expenditure. We further find that a 5% postal price increase, such as the one introduced in January 2006 reduces revenue collected from US households by $215 million and imposes an aggregate welfare loss on US households of $333 million.

Executive summary

The Postal Accountability and Enhancement Act (PAEA), which became law on December 20, 2006, will implement a modern system of regulation for the United States Postal Service (USPS) to ensure its financial viability into the distant future. A major motivation for the PAEA was to provide the USPS with greater pricing flexibility to respond the increasing competition it faces. To this end, the PAEA established two USPS product categories: Market-Dominant products (what the USPS calls "mailing services") and Competitive products (what the USPS calls "shipping services").

For Market-Dominant products, the PAEA caps the maximum volume-weighted average price increase by class of mail at the rate of change of the Consumer Price Index (CPI). The prices of competitive products are not subject to the cap, but these prices must at least recover the incremental cost of each product and make an appropriate contribution to the common costs of the USPS. To maximize the contribution all products make to fixed and common costs recovery, the USPS must have a complete understanding of the demand for its products and the nature of its production costs to exploit fully the pricing flexibility granted by the PAEA. This paper characterizes the structure of demand for an important class of USPS customers–households.

We first identify a steady decline in the share of USPS revenues coming from the household sector over the period 1986 to 2004. The tremendous increase in the access of households to the Internet and a steady decline in the price of long-distance telephone service relative to the price of postal delivery services over this time period are both likely to have adversely impacted the household-level demand for postal delivery services. A major goal of our empirical work is to determine the relative impact of these two factors on the household-level demand for postal delivery services. To this end, we specify and estimate an econometric model of the household-level demand for postal delivery services that accounts for the distinction between expenditure on and consumption of postal delivery services, the decision of the household to purchase a personal computer and the impact of this purchase on its demand for postal delivery services, the impact of the relative price of telephone services on the household's demand for postal delivery services, and the relationship between the household's total non-durable expenditures and its demographic characteristics.

Our estimates predict revenue reductions from the US household sector from future postal rate increases, telephone services price reductions, and adoption of personal computing technology by US households, although the computer ownership elasticity for the post-2000 period implies that future computer adoption at the household level will not lead to revenue reductions as large

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as those associated with the adoptions that occurred during the period 1994 to 2000. We also find that a 5% postal price increase such as the one introduced in January 2006 reduces revenue collected from US households by $215 million and imposes an aggregate welfare loss on US households of $333 million.

These results are not encouraging for the future financial viability of the USPS even with the pricing flexibility provided by the PAEA. Unless the demand for USPS services from other segments of the economy picks up this slack, the USPS is likely to experience revenue reductions in the future even with significant rate increases for products purchased by the household sector. The remainder of the paper explores the potential for other USPS products to provide the revenues needed for the future financial viability of the USPS. We conclude that the USPS will continue to face competition from electronic alternatives for virtually all of the services it provides. Our empirical results suggest that the USPS should focus future postal price increases on the products not intensively used by the household sector such as Presorted First-Class Mail and Standard Mail, because price increases aimed at achieving greater revenue from single-piece First-Class Mail (the letter-delivery product used by households) may be self-defeating given our model estimates.

1. Introduction

The past fifteen years have seen a tremendous increase in household-level access to the Internet and a steady decline in the price of long-distance telephone services relative to postal delivery services, both of which are likely to have impacted the demand for traditional postal delivery services. For example, rather than sending a hard copy of a document using the United States Postal Service (USPS), consumers can send an electronic copy of the document via e-mail. Monthly bills for many goods and services can now be paid online, further reducing the household-level demand for the services of the USPS. The price of a first-class stamp, on the other hand, has increased from 22 cents effective February 17, 1985 to 39 cents effective January 8, 2006, while the price per minute of a domestic long-distance telephone call has declined to close to zero over the same time period. Because a long-distance call can substitute for postal delivery services, this relative price increase is also likely to reduce household-level demand for postal delivery services.

In this paper we first document the shift in the aggregate household-level consumption of postal delivery services from 1986 to 2004 resulting from all of these factors. We then quantify the extent to which this shift can be attributed to the appearance of alternative modes of communication made possible by the Internet versus the concomitant rise in the relative price of postal delivery services. To this end, we estimate a model of the household-level demand for postal delivery services and compute own-price and cross-price elasticities, as well as an elasticity of postal demand with respect to computer ownership.

A major concern in all industries with a universal service obligation is the distributional impact of price increases. Because our model of the demand for postal delivery services satisfies the restrictions implied by utility-maximizing behavior, we can compute both the demand response and the household-level welfare impact associated with any postal price increase. Our demand system is used to compute the household-level compensating variation associated with a 5% postal price increase, the magnitude enacted on January 8, 2006. Based on these results, we determine the distribution of the welfare impact of this price increase across US households and assess the regressivity of this price increase for the household sector. We also use our model to estimate the aggregate welfare loss and the change in total USPS revenue collected from the household sector.

Our econometric analysis uses the United States (US) Bureau of Labor Statistics (BLS) *Consumer Expenditure Survey* (CEX). The CEX consists of two distinct surveys administered to different samples of US households: the *Diary Survey*, for which a household keeps a one-week diary of all expenditures over two consecutive weeks; and the *Interview Survey*, for which a household is interviewed for their quarterly purchases of a range of goods and services over a 15-month period. To the best of our knowledge, the Diary Survey is the only publicly available data with household-level information on postage expenditure for a national probability sample of US households. In addition, it contains detailed information on household demographics and expenditure on telephone services and non-durable goods. For this reason, the Diary Survey is the primary source of data.

Using the Diary Survey for our analysis, however, entails four empirical challenges. First, this data set lacks information on personal computer ownership and Internet access. Second, the purchases of each household in the Diary Survey are recorded only for two consecutive weeks, which leads to a potential discrepancy between the observed postage purchases and actual (but unobserved) consumption of postal delivery services. Third, though the Diary Survey contains a rich set of variables on household characteristics, there may be unobserved heterogeneity that determines both computer ownership decision and postal demand. Finally, because the Diary Survey only covers a two-week period, there is likely to be correlation between the household's observed total non-durable expenditures for this time period and unobserved household characteristics that influence its purchase decisions. We develop a general econometric model of the household-level demand for postal delivery services consistent with utility-maximizing behavior that addresses all of these empirical challenges.

To address the first problem, we use the Interview Survey because it collects household-level information on the ownership of durable goods such as personal computers by the same demographic variables as the Diary Survey. We treat computer ownership as an unobserved binary variable and employ a two-sample maximum likelihood (2SML) procedure to estimate our demand system. The Interview Survey is used to estimate a model for the probability of personal computer ownership for each year in the sample as a function of household characteristics common to both surveys. Conditional likelihood functions for each household in the Diary Survey – one for the case that the household owns a computer and the other for the case that the household does not own a computer – are then constructed. Using these two conditional likelihood functions and the probability of computer ownership from the Interview Survey for that household, we compute the unconditional likelihood for each household in the Diary Survey.

The second problem our econometric model must address is that a household's purchases of postal delivery services may differ substantially from its actual consumption of these services. For example, a household may have previously purchased a roll of stamps, but it now uses them periodically in consuming postal delivery services. This household may then report zero expenditure on postage during the period of the Diary Survey, despite positive consumption of postal delivery services during this period. The empirical relevance of the distinction between postal delivery services purchases and consumption is illustrated by the fact that approximately 70% of all households in our sample do not purchase any postage during the two-week Diary Survey period. The discrepancy between purchases and consumption can create various complications for the proper recovery of the structure of household-level demand. To address this problem, we posit that the observed purchases of postal delivery services are the combination of a frequency of purchase process and unobserved consumption. Accordingly, we estimate an econometric model of the frequency of postage purchase jointly with a model of household-level demand for postal delivery services.

The third empirical challenge is that unobserved heterogeneity is likely to impact the household's decisions about postage consumption, the frequency of postage purchase, and computer ownership. The fourth empirical challenge is that frequency of purchase decisions may impact the consumption of other non-durable goods within the two-week period covered by the Diary Survey. To address both of these problems, we include a common unobservable factor with a different coefficient in each of the four equations for, respectively, the household's decision to own a computer, the decision to purchase postage, the choice of the level of postage consumption, and the choice of the level of total non-durable good expenditures within the two-week Diary Survey sample period. We then model unobserved heterogeneity as a random effect that enters all four equations simultaneously. We construct likelihood functions conditional on this unobserved heterogeneity and then compute the unconditional likelihood by integrating with respect to the density of this random variable. We estimate the final model using both the Diary Surveys and the Interview Surveys from the 1986–2004 CEX.

Because the CEX provides a weight giving the number of households in the US represented by each household in the Diary Survey sample each year, we can use these weights to compute estimates of the aggregate household-level consumption of postal delivery services as well as the aggregate own-price and cross-price elasticities of the demand for postal delivery services. This enables us to assess the likely revenue consequences to the USPS from future postal price increases given the aggregate demand relations implied by our household-level demand estimates. Across a variety of specifications, we find that the aggregate household-level demand for postal delivery services is own-price elastic, implying that postal price increases actually reduce total postal revenues from the household sector. The aggregate own-price elasticity derived from our parameter estimates implies that a 5% increase in the price of postage leads to a 3.24% reduction in the revenue that the USPS can expect to receive from US households.

We can also compute an aggregate elasticity of the household-level demand for postal delivery services with respect to computer ownership. Using the elasticity estimate for the 1994–2000 period[1] when household-level Internet adoption was rapidly expanding, a 13% increase in the percentage of US households with personal computers (the average annual percent increase in the fraction of households with computers from 1994 to 2000) yields a 2.8% decline in annual USPS revenue from the household sector. This revenue reduction is approximately equal to the decline in USPS revenue brought about by the 5% price increase. The elasticity for the 2000–2004 period, when rate of Internet adoption slowed down, implies that a 6.4% increase in the fraction of US households with personal computers (the average percent increase in the fraction of households with computers from 2001 to 2004) yields a 0.5% reduction in USPS revenues. This difference between the impact of computer ownership on postal delivery services expenditure from 1994 to 2000 and that from 2001 to 2004 is consistent with the view that by 2004 most of the electronic substitution from traditional postal delivery services to online substitutes had occurred.

Using the household-level demand functions implied by our model and the CEX weights, we estimate that the January 8, 2006 rate increase reduced the annual revenue collected from US households by $215 million and imposed an aggregate annual welfare loss on US households of $333 million. Because we have computed the compensating variation associated with this price increase for each household in our post-2000 sample, we can also determine which households were most harmed by these postal price increases. From regressions predicting the logarithm of the household's compensating variation divided by its total non-durable expenditure as a function of the its demographic characteristics, we find that more highly educated households, with older heads, with more members over 65, and living in standard metropolitan areas had compensating variations that were larger relative to their total non-durable expenditure.

The remainder of the paper proceeds as follows. Section 2 describes the contents of our data sources and provides summary statistics to motivate our econometric modeling exercise. Section 3 develops our four-equation econometric model of computer ownership, postage purchase, postage demand, and total non-durable expenditures consistent with household-level utility maximizing behavior that incorporates correlated unobserved heterogeneity across the four equations. This section also derives the likelihood function and describes our estimation procedure. Section 4 presents estimation results and the results of our counterfactual price increase for postal purchases and household-level and aggregate welfare. Section 5 discusses the implications of these results for postal price-setting and the future of the USPS.

2. Data and descriptive statistics

This section first discusses the two major data sources used in the analysis. We then compute estimates of total annual household expenditure on postal delivery services and telecommunications services and discuss potential economic drivers of these changes over the period 1986–2004, particularly focusing on impact of the increase in the price of postal delivery services (relative to the price of substitutes for USPS services such as telecommunications services) and the increase in the percent of households with personal computers.

2.1. Consumer expenditure survey: Diary survey and interview survey

This paper uses two surveys from the *Consumer Expenditure Survey* (CEX) collected by the Bureau of Labor Statistics (BLS). The CEX is a national probability sample of US households generated from the 1980 Census 100% detail file. The BLS administers two distinct surveys: the *Diary Survey* and the *Interview Survey*. Both surveys contain information on household demographic characteristics. These two surveys are conducted separately using different questionnaires and independent samples. The Diary Survey collects all expenditure of a household for two consecutive one-week periods, whereas the Interview Survey collects quarterly expenditure on selected goods and services by the household. It is important to bear in mind that postal delivery services expenditure is only recorded in the Diary Survey, while information on durable goods holdings such as computers is included in the Interview Survey but not in the Diary Survey.

The source of consumption data for our analysis is the Diary Survey. Each sampled household completes a weekly diary document listing every purchase – the good and the amount spent – made within that one week period (except expenditure incurred while away from home, overnight or longer). Every year the Diary sample is re-drawn, with each day of the week having an equal probability of being the first day of the reference week for a sampled household. With the exception of the last six weeks of the year, when

[1] Note that Mosaic, the first popular web browser, was introduced in 1993, and that Netscape released its first web browser in late 1994. For this reason, we consider the period starting from 1994.

Table 1
Average expenditure and share from the consumer expenditure diary survey

Year	Postal expn. ($)			Postal share			Telephone expn. ($)			Telephone share			No.
	Mean (1)	S.D.[a] (2)	Max (3)	Mean (4)	S.D. (5)	Max (6)	Mean (7)	S.D. (8)	Max (9)	Mean (10)	S.D. (11)	Max (12)	Obs. (13)
1986	2.35	6.69	200.58	0.0073	0.028	1.00	15.88	32.76	400.00	0.039	0.077	0.82	5950
1987	2.62	9.56	399.98	0.0076	0.028	1.00	17.85	36.41	516.80	0.043	0.082	0.84	6094
1988	2.80	8.33	357.78	0.0086	0.031	1.00	18.45	36.55	429.65	0.043	0.083	0.75	5351
1989	3.01	8.23	214.00	0.0082	0.027	0.89	19.52	41.75	1096.98	0.042	0.081	0.95	5411
1990	2.98	6.93	87.00	0.0081	0.026	1.00	20.87	44.43	785.67	0.043	0.082	0.78	5560
1991	2.59	7.29	120.55	0.0055	0.017	0.43	21.59	44.97	600.00	0.042	0.082	0.80	5671
1992	2.63	7.81	222.78	0.0058	0.020	0.75	24.28	47.97	729.16	0.046	0.085	1.00	5548
1993	2.41	10.70	590.11	0.0048	0.017	0.37	24.30	49.92	742.00	0.045	0.087	0.86	5431
1994	2.24	7.18	157.32	0.0049	0.019	0.72	26.94	52.40	633.87	0.050	0.091	0.90	5013
1995	2.66	7.63	90.60	0.0053	0.018	0.47	28.14	51.90	575.22	0.052	0.094	1.00	4168
1996	2.81	13.01	686.40	0.0051	0.019	0.54	28.72	55.23	820.59	0.050	0.092	1.00	4585
1997	2.84	9.19	166.40	0.0054	0.019	0.34	27.55	57.85	654.77	0.047	0.090	1.00	4969
1998	2.86	9.45	168.00	0.0056	0.019	0.41	26.91	56.91	1071.56	0.045	0.090	0.88	5437
1999	2.63	9.95	296.85	0.0049	0.023	1.00	29.79	60.20	1200.00	0.049	0.092	1.00	7044
2000	2.52	11.29	708.82	0.0043	0.017	0.55	32.23	61.26	787.65	0.050	0.090	0.81	7078
2001	2.50	9.01	320.25	0.0042	0.015	0.47	33.61	61.91	883.00	0.051	0.089	0.87	7220
2002	2.85	9.01	206.99	0.0049	0.016	0.30	34.57	65.12	1597.59	0.052	0.089	0.84	7345
2003	2.96	10.51	247.75	0.0050	0.019	0.51	34.24	62.19	1004.06	0.051	0.088	0.85	7432
2004	3.15	10.52	214.92	0.0049	0.020	0.54	36.47	69.18	1076.04	0.049	0.085	0.90	6813

Note that the minimum value of each variable is zero.
[a] S.D. denotes standard deviation.

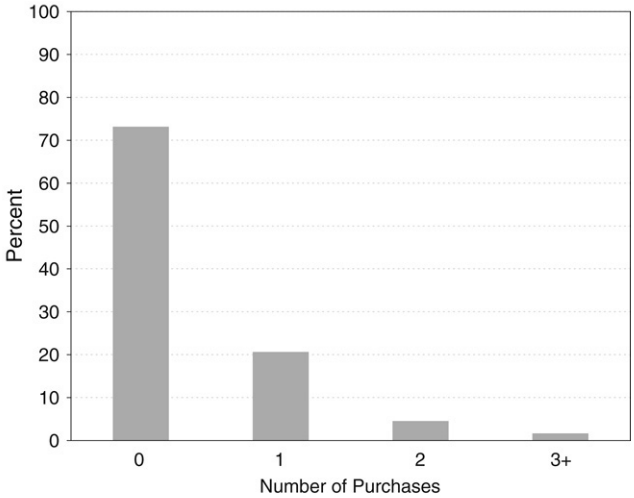

Fig. 1. Postage purchases over a two-week period.

the Diary sample size is doubled to increase the coverage of expenditure unique to the holiday season, the number of Diary Surveys administered is uniformly distributed throughout the year.

`Postage` in the Diary Survey includes not only stamps, but also most postal delivery services from the USPS — airmail stamps, certified mail, registered mail, stamps for collecting, stamped post cards, stamped envelopes, books of stamps, special delivery postage fees and handling fees, PO box rental, and postal money order fees.[2] For our analysis, total postage expenditure for each household is the sum of all purchases of postage during the two-week sample interval. Fig. 1 presents a histogram of the number of purchases of postage during the two-week diary period. From the figure, it is clear that the vast majority of households that purchase postage during their Diary Survey period make only one purchase. For this reason, the subsequent empirical analysis focuses on the decision to purchase within the two-week period, rather than on the number of purchases made.

The Interview Survey is the source for computer ownership data at the household-level. Beginning with the 1988 survey, households were asked if they owned a personal computer. Because the Diary Survey and Interview Survey collect the same household characteristics, these variables can be used to link households that share these characteristics across the Interview Survey and Diary Survey samples.

2.2. Changes in postage expenditure and potential explanations

We now examine changes in household-level expenditures on postal delivery services from 1986 to 2004. To do so, we first compute the sample average of household-level postage expenditure from the Diary Survey. For the purpose of comparison, we also compute the same statistics for telephone expenditure. Using the CEX sampling weights and the household-level expenditure contained in the Diary Survey, we then estimate annual aggregate expenditure from the household sector on postage and telecommunication services. We compare the aggregate expenditure on postage to total USPS revenue and compute estimates of the share of USPS revenue coming from the household sector.

Table 1 presents descriptive statistics of household-level expenditure on postage and telephone services during the two-week Diary sample period. The table reports the sample averages, standard deviations, and maximum values for the Diary samples in each year. Minimum values are not reported in the table because all of them are zero. For each household in the Diary Survey, we also compute the shares of postage and telephone in total expenditure on non-durable goods, where we define non-durable goods as the combination of postage, telephone, and other non-durable goods that the BLS includes in the Consumer Price Index (CPI) for non-durable goods.[3] Table 1 reports summary statistics of these shares as well.

[2] This information on postage can be obtained by sending an e-mail inquiry to cexinfo@bls.gov.

[3] According to the document on the CPI item aggregation tree which we obtained by contacting the BLS division of consumer prices and price indexes, the CPI for non-durables is constructed by aggregating the following items: food, beverages, apparel, fuel oil and other household fuels, window and floor coverings and other linens, housekeeping supplies, motor fuel, medical care commodities, audio discs and video, pets and pet products, photographic equipment and supplies, recreational reading materials, other recreational goods, educational books and supplies, tobacco and smoking products, personal care products, and miscellaneous personal goods. These items correspond to expenditure category in the CEX. See also the CEX documentation for more details on the definition of this spending category.

Table 2A
Nominal postal mail revenue and estimated annual household expenditure

Year	Estimated household postage expenditure		Estimated household telephone expenditure		USPS mail revenue	
	Aggregate ($ billion) (1)	Mean ($) (2)	Aggregate ($ billion) (3)	Mean ($) (4)	Total[a] ($ billion) (5)	% Share of households (6)
1986	5.06	58.08	36.54	419.75	29.12	17.36
1987	5.80	66.55	41.12	471.75	30.50	19.02
1988	5.81	65.46	42.60	479.93	33.92	17.13
1989	6.62	73.50	44.93	498.74	36.67	18.06
1990	6.38	69.88	50.11	549.13	37.89	16.83
1991	5.77	62.30	51.95	560.92	41.92	13.76
1992	6.06	64.13	59.79	633.00	44.72	13.54
1993	5.90	62.71	60.81	646.60	45.91	12.85
1994	5.11	54.96	64.94	698.72	47.74	10.70
1995	5.72	67.26	61.99	728.56	52.49	10.90
1996	6.25	70.23	68.24	766.86	54.54	11.46
1997	6.05	67.92	64.54	724.60	56.27	10.75
1998	6.35	64.39	68.99	699.42	58.27	10.90
1999	6.51	64.75	78.72	783.27	60.42	10.77
2000	6.31	62.78	83.52	830.83	62.28	10.13
2001	6.31	61.18	90.41	876.72	63.43	9.95
2002	7.55	72.57	92.97	893.32	63.76	11.85
2003	7.85	72.79	95.16	882.82	65.70	11.94
2004	8.28	78.54	101.31	960.91	65.87	12.57

Estimated from the Consumer Expenditure Diary Survey samples, using the CEX weights.
[a] Taken from *Revenue, Pieces, and Weight Report* and Annual Reports of the United States Postal Service.

Column 1 in the table shows an initially increasing average expenditure on postal delivery services from 1986 to 1989 and then a steady decline from 1990 to 1994, which is followed by a modest increase from 1995 to 1998 and then a slight decline from 1999 to 2001, with an increase in each year after 2001. In contrast, telephone services expenditures reported in column 7 show a steady increase through 2004, except for slight declines in 1997 and 1998. Columns 4 and 10 in the table present similar trends in the shares of these expenditures in total non-durable goods expenditure. These changes suggest potential substitution between postal demand and telecommunication demand.

We then use the CEX sampling weights and estimate USpopulation values for total annual postage and telephone expenditure for each year from 1986 to 2004.[4] Table 2A reports both aggregate values and household-level mean values estimated from the Diary Survey samples. The table shows an increase in annual postage expenditure from 1986 to 2004, with modest declines in some years (columns 1 and 2). Annual expenditure on telephone services, on the other hand, increased substantially over the sample period (columns 3 and 4). To account for overall price increases, Table 2B reports the same values as in Table 2A, deflated by the CPI for all urban consumers.[5] Unlike changes in nominal values, columns 1 and 2 in Table 2B show a downward trend in real postal expenditure through 2001 with moderate fluctuations, followed by a slight increase until 2004. In contrast, real expenditure on telephone services continuously increased from 1986 to 2004.

Table 2A also lists the total nominal mail revenue for the USPS for each year from 1986 to 2004.[6] To compute estimates of the share of USPS mail revenue coming from the household sector, we compare aggregate household expenditure on postage (column 1) to total USPS mail revenue (column 5). The percentage of total USPS mail revenue from household sector, the ratio of column 1 to column 5 times 100, are reported in column 6 in the table. Although nominal revenue obtained from US households has increased from 1986 to 2004, the share of USPS revenue coming from the household sector had declined significantly from a high of 19% in 1987 to 10.7% in 1994. Despite several postage price increases from 1994 to 2001, this share remained constant at approximately 10%. After 2001, however, the share has increased moderately.

What explains these changes in household-level expenditure on postal delivery services? One explanation is the steady increase in the relative price of postage compared to that of other modes of communication. Fig. 2 plots the monthly CPIs for postage and the composite of local and long-distance telephone services, non-seasonally adjusted and normalized to have prices in January 1986 equal to one.[7] The figure also plots real yearly averages of household-level expenditures on postage, presented in column 2 of Table 2B. This figure shows the large relative price increase in postage versus telephone services over the sample period. Note that each discrete jump in the postage price index coincides with each change in postal prices by the USPS. Though the rate increases in 1995 and 2001 coincided with modest increases in household-level postal expenditure, most increases in the price of postage are accompanied by reductions in household expenditure on postal delivery services. This suggests that a price-elastic demand has brought about reductions in postal expenditure in response to the relative price increase.

Other factors, however, can explain the changes in household-level postal expenditure as well. In particular, computer ownership grew significantly over the sample period and could have shifted the demand for postal delivery services. Fig. 3 plots estimates of the annual percentage of US households that own personal computers from 1988 to 2004. These estimates are constructed as described in the Interview Survey documentation using the sampling weight for each household in our sample and the indicator variable for whether that household owns a computer. The figure shows a steadily increasing fraction of US households owning computers each year during our sample period. Note that the downward trend in household-level postal expenditure is also accompanied

4 See the documentation for each year of the Consumer Expenditure Diary Survey for the procedure to estimate the population value of total expenditure on any good, using household expenditure on the good and the sampling weight from the Diary Survey.

5 This price index is the seasonally unadjusted CPI for all urban consumers: US city average for all items, obtained from the BLS web-site.

6 These figures are taken from the *Revenue, Pieces, and Weight Report* and Annual Reports by the United States Postal Service.

7 These price indexes are the seasonally unadjusted Consumer Price Index for all urban consumers: US city average for postage and telephone services, obtained from the BLS web-site.

Table 2B
Real postal mail revenue and estimated annual household expenditures (in 1986 Dollars)

Year	Estimated household postage expenditure		Estimated household telephone expenditure		USPS mail revenue	
	Aggregate ($ billion) (1)	Mean ($) (2)	Aggregate ($ billion) (3)	Mean ($) (4)	Total ($ billion) (5)	% Share of households (6)
1986	5.06	58.08	36.54	419.75	29.12	17.36
1987	5.60	64.21	39.67	455.14	29.43	19.02
1988	5.38	60.64	39.46	444.63	31.43	17.13
1989	5.85	64.97	39.71	440.82	32.41	18.06
1990	5.35	58.59	42.02	460.48	31.77	16.83
1991	4.64	50.13	41.80	451.37	33.73	13.76
1992	4.73	50.09	46.71	494.49	34.93	13.54
1993	4.47	47.56	46.12	490.43	34.82	12.85
1994	3.78	40.64	48.02	516.73	35.31	10.70
1995	4.12	48.37	44.58	523.95	37.75	10.90
1996	4.37	49.06	47.67	535.68	38.10	11.46
1997	4.13	46.38	44.07	494.81	38.42	10.75
1998	4.27	43.29	46.39	470.28	39.18	10.90
1999	4.28	42.60	51.78	515.29	39.75	10.77
2000	4.02	39.96	53.16	528.80	39.64	10.13
2001	3.90	37.86	55.95	542.57	39.25	9.95
2002	4.60	44.21	56.64	544.23	38.84	11.85
2003	4.67	43.36	56.68	525.85	39.13	11.94
2004	4.80	45.57	58.78	557.52	38.22	12.57

Estimated from the Consumer Expenditure Diary Survey samples, using the CEX weights. Real values are obtained by deflating nominal values in Table 2A by the seasonally unadjusted Consumer Price Index for all urban consumers — US city average for all items.

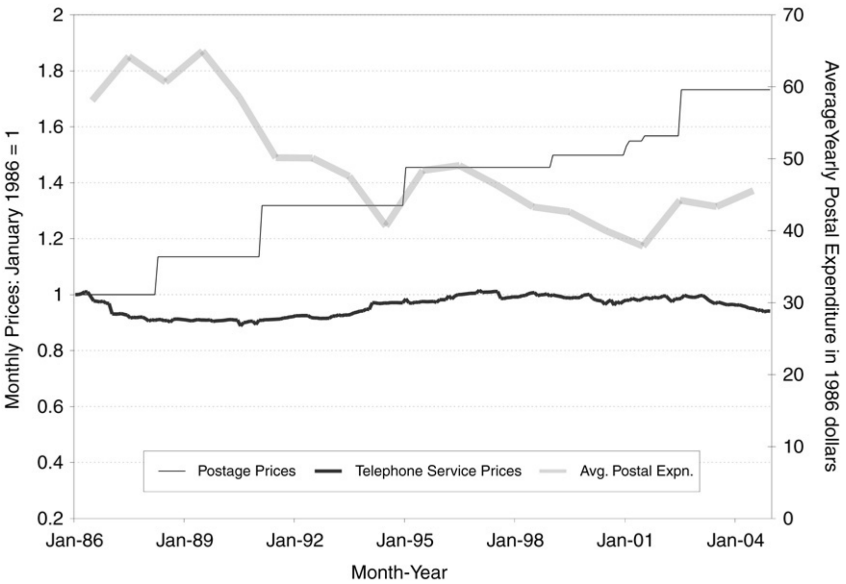

Fig. 2. Movements in postage and telephone prices (Refer to the Consumer Price Index by the Bureau of Labor Statistics.) and household-level average yearly postal expenditure (The figure plots household-level average yearly postal expenditure in 1986 dollars estimated in column 2 of Table 2B.).

by this diffusion of personal computers across the population of US households.

Though these descriptive statistics provide evidence for the validity of several potential explanations for the observed changes in household-level postal delivery services expenditure, they do not allow us to quantify their relative contributions. In order to distinguish between these explanations in an internally consistent manner, we require a model of the household-level demand for postal delivery services. The next section discusses the econometric methodology we use to estimate this demand system given the data at our disposal.

3. Empirical framework

This section presents our econometric model to study the structure of the household-level demand for postal delivery services. We first model the probability of computer ownership and describe our two-sample maximum likelihood (2SML) method to combine data from the Diary Survey and the Interview Survey. To develop our model of household-level postage expenditure, we then specify equations for postage purchase, postage consumption, and total non-durable expenditure. We account for the important distinction between observed purchases and the unobserved consumption of postal delivery services. We also allow for unobserved heterogeneity in these three equations, as well as in the equation for the probability of computer ownership. This controls for common unobserved factors that affect a household's decisions about computer ownership, postal delivery services purchase frequency and consumption, and total non-durable expenditure. Finally, we construct the likelihood function for an econometric model that encompasses all these features. We complete this section by discussing which variables enter each equation of the model.

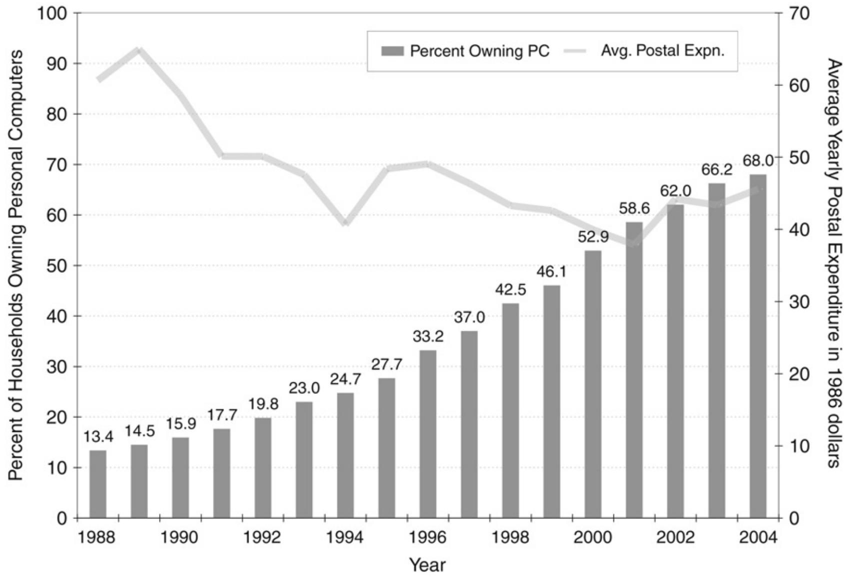

Fig. 3. US population percentages of personal computer ownership (Estimated from Consumer Expenditure Interview Survey samples, using the CEX weights.) and average yearly postal expenditure (The figure plots household-level average yearly postal expenditure in 1986 dollars estimated in column 2 of Table 2B.).

3.1. Model for probability of computer ownership

We use all household characteristics common to the Interview Survey and the Diary Survey to estimate the probability of computer ownership using household-level data from the Interview Survey. The parameter estimates from this model are of some independent interest given the rapid increase in the estimated fraction of US households owning personal computers — from 13.4% in 1988, the first year in which the Interview Survey collected this information, to 68.0% in 2004, the last year of our sample. To allow for changes over time in the relationship between these demographic variables and a household's computer ownership decision, we estimate a different model for each year from 1988 to 2004.

We posit that a household owns a personal computer if the net benefit of using a computer becomes positive. Specifically, we assume that household i owns a computer if $C_i^* \geq 0$ and does not if $C_i^* < 0$, where C_i^* denotes the latent propensity to own a computer, reflecting the net benefit of computer ownership. The event of computer ownership is denoted by the indicator variable C_i, which takes on the value 1 if the household owns a computer and zero otherwise. We model the propensity to own a computer across different households as a linear index in observed household characteristics plus unobserved heterogeneity. Let X_{ci} denote the vector of household characteristics for household i in the Interview Survey. We use the subscript c to indicate variables (or coefficients) related to computer ownership.

The propensity to own computers is therefore determined by

$$C_i^* = X_{ci}'\beta_c + \theta_i + \epsilon_{ci}, \tag{1}$$

where ϵ_{ci} is an independent identically distributed $N(0, \sigma_{\epsilon_c}^2)$ random variable across households and θ_i is an independent identically distributed $N(0, \sigma_\theta^2)$ random variable that is distributed independently of ϵ_{ci}. Note that we decompose unobserved heterogeneity into ϵ_{ci} and θ_i. The error term ϵ_{ci} is an idiosyncratic component specific only to the propensity to own computers. The error term θ_i is included in Eq. (1) to account for the fact that there may be a common unobservable component determining not only the household's probability of owning computers, but also its probability of purchasing postage, the demand for postage, and the level of total non-durable expenditure for the two-week period.

The log-likelihood function for our model of computer ownership for each year is given by

$$L(b_c^*) = \sum_{i=1}^{N} C_i \times \ln(\Phi(X_{ci}'b_c^*)) + (1 - C_i) \times \ln(1 - \Phi(X_{ci}'b_c^*)), \tag{2}$$

where N is the number of households in the Interview Survey during the year under consideration, $\Phi(\cdot)$ is the standard normal distribution function, and $\beta_c^* = \frac{\beta_c}{\sqrt{\sigma_\theta^2+\sigma_{\epsilon_c}^2}}$. Let $\hat{\beta}_c^*$ denote the maximum likelihood estimate of β_c^*, which is obtained by maximizing the likelihood function given in (2) with respect to b_c^*. Under the usual regularity conditions, $\hat{\beta}_c^*$ is a consistent estimate of $\beta_c^* = \frac{\beta_c}{\sqrt{\sigma_\theta^2+\sigma_{\epsilon_c}^2}}$. An estimate of $\Pr(C_i = 1|X_{ci})$, the probability of computer ownership given X_{ci}, can be computed as $\Phi(X_{ci}'\hat{\beta}_c^*)$.

Table 3 gives the maximum likelihood estimates for 1988 and 2004. As noted above, to allow for changes in the relationship between the probability of computer ownership and household-level demographics over time, we estimated a different probit model for each year from 1988 to 2004. To compute the probability of computer ownership for each household during each year of the Diary Survey, we use the probit model parameter estimates from that same year's Interview Survey data. Because computer ownership information was not collected for 1986 or 1987 in the Interview Survey, the parameter estimates from the model estimated for 1988 are used to compute estimated probabilities of computer ownership for all observations from the Diary Surveys in 1986 and 1987.

These estimated probabilities of computer ownership functions allow us to use the 2SML method to link C_i across the Interview Survey and the Diary Survey. To explain the method, let Y_i denote a vector of random variables. In the model developed in the next subsection, Y_i includes D_i, the indicator variable for postage purchase, w_i, the share of postal expenditure, and M_i, the total expenditure on non-durable goods. We define the conditional density function given C_i to be $f(Y_i|C_i, X_i; \Delta)$, where X_i is a vector of variables common to two data sets, and Δ is a vector of parameters to be estimated.

Using only the Diary Survey, however, does not allow us to estimate Δ because C_i is not observed. If we instead use the

Table 3
Selected results from computer ownership probits

Variable	Estimates for sample year		
	1988	1999	2004
Constant	−2.3475 (0.5268)	−2.3327 (0.3416)	−1.7630 (0.3120)
February	−0.0258 (0.1211)	0.1059 (0.0787)	−0.0524 (0.0825)
March	0.1752 (0.1182)	0.0807 (0.0783)	0.0854 (0.0838)
April	−0.0127 (0.1208)	0.1044 (0.0789)	−0.0421 (0.0838)
May	−0.0611 (0.1200)	0.1672 (0.0793)	−0.0448 (0.0842)
June	0.0388 (0.1185)	0.0516 (0.0787)	0.0630 (0.0834)
July	0.0296 (0.1189)	0.1475 (0.0792)	0.0016 (0.0832)
August	0.2540 (0.1151)	0.1995 (0.0793)	0.0917 (0.0848)
September	0.2005 (0.1175)	0.1662 (0.0791)	−0.0706 (0.0843)
October	0.0830 (0.1181)	0.2336 (0.0792)	0.0567 (0.0836)
November	−0.1555 (0.1268)	0.1894 (0.0789)	0.0292 (0.0837)
December	0.0479 (0.1193)	0.2163 (0.0777)	−0.0186 (0.0839)
Northeast	0.1688 (0.0708)	0.1645 (0.0518)	0.1194 (0.0560)
South	0.0323 (0.0691)	0.0853 (0.0441)	−0.0586 (0.0466)
West	0.1117 (0.0695)	0.2822 (0.0466)	0.1141 (0.0506)
smsa	−0.1233 (0.0715)	−0.1514 (0.0463)	0.0246 (0.0477)
home.owner	0.0710 (0.2937)	0.3666 (0.2259)	0.8549 (0.2280)
Renter	−0.0790 (0.2943)	0.1263 (0.2267)	0.5423 (0.2279)
dorm.resident	0.6581 (0.3953)	1.0817 (0.2822)	1.5319 (0.3179)
family.size	−0.0772 (0.0549)	−0.0184 (0.0366)	0.0186 (0.0372)
pers.lt.18	0.2003 (0.0578)	0.0746 (0.0396)	0.0215 (0.0429)
pers.gt.64	−0.0425 (0.0910)	0.0355 (0.0544)	−0.1987 (0.0539)
#earners	0.0857 (0.0505)	0.1499 (0.0362)	0.0954 (0.0409)
#vehicles	0.0595 (0.0162)	0.0557 (0.0131)	0.0903 (0.0158)
White	0.0101 (0.3146)	0.2042 (0.1702)	0.1154 (0.1026)
Black	−0.0182 (0.3269)	−0.1977 (0.1775)	−0.1264 (0.1125)
Male	0.1776 (0.0668)	0.0503 (0.0359)	−0.0339 (0.0378)
Married	−0.4678 (0.2197)	−0.5407 (0.1383)	−0.0817 (0.1258)
hs.grad	0.1821 (0.0885)	0.4945 (0.0562)	0.4508 (0.0528)
less.college	0.5271 (0.0896)	0.9134 (0.0598)	0.9747 (0.0587)
college.grad	0.7543 (0.0936)	1.2127 (0.0573)	1.1816 (0.0577)
Age	2.1773 (1.3347)	2.9354 (0.6779)	1.9867 (0.6346)
Age^2	−3.3312 (1.4999)	−4.3518 (0.7168)	−3.2882 (0.6558)
spouse.age	2.0801 (1.1148)	2.8253 (0.6583)	0.9535 (0.6124)
spouse.age^2	−1.8624 (1.3593)	−2.2831 (0.7524)	−0.4089 (0.7063)
prof.occupation	0.2634 (0.0712)	0.1599 (0.0591)	0.1158 (0.0739)
tech.occupation	0.1098 (0.0723)	0.0298 (0.0954)	0.1386 (0.1107)
self.employed	0.1823 (0.1013)	−0.0042 (0.1265)	0.4072 (0.1868)
retired	0.2214 (0.1425)	−0.1853 (0.0648)	−0.0556 (0.0601)
work.hours	−0.0015 (0.0019)	0.0000 (0.0012)	−0.0030 (0.0013)
spouse.work.hours	0.0013 (0.0019)	−0.0007 (0.0014)	−0.0021 (0.0017)
positive.income	0.0437 (0.0111)	0.0470 (0.0055)	0.0598 (0.0066)
negative.income (dummy)	0.0981 (0.0915)	0.2265 (0.0490)	−0.0048 (0.3140)
No. observations	5096	7643	7757
Log-likelihood function value	−1733.064	−4024.208	−3469.415

Standard errors are in parentheses.

Interview Survey as well to estimate the probability of computer ownership given common variables, we can estimate Δ based on the following unconditional density function:

$$f(Y_i|X_i;\Delta) = f(Y_i|C_i=1,X_i;\Delta)\times\Pr(C_i=1|X_i) + f(Y_i|C_i=0,X_i;\Delta)\times\Pr(C_i=0|X_i).$$

Even though we do not observe C_i in the Diary Survey, we can still construct the two conditional likelihood functions — one for $C_i = 1$ and the other for $C_i = 0$. Because we use a parametric estimator for the probability of computer ownership, we can compute the unconditional likelihood for each household in the Diary Survey and estimate Δ by applying a conventional maximum likelihood method. This 2SML estimator satisfies all of the regularity conditions of the conventional ML estimator.[8] The next subsection describes how we utilize this two-sample estimation methodology in our four-equation econometric model with common unobserved heterogeneity impacting all four endogenous variables.

3.2. Econometric model of postal delivery services expenditure

Our econometric model of postage expenditure accounts for the distinction between purchases and consumption of postal delivery services, the correlation between the four decisions made by the household (computer ownership, purchase of postage, consumption of postage, and total non-durable spending), the infrequency of purchases of postal delivery services and other non-durable goods within the two-week Diary Survey period, and is consistent with utility-maximizing behavior at the household-level. The demand model is specified with the share of postage expenditure in total non-durable expenditures as the dependent variable.

We require the following notation to describe the model. Let D_i denote the indicator random variable that equals 1 if the household i purchases postage within the two-week sampling interval of the Diary Survey and 0 otherwise. This indicator variable is determined according to the following model.

$$D_i^* = X_{di}'\beta_d + \rho_d\theta_i + \epsilon_{di}, \tag{3}$$

where ϵ_{di} is an independent identically distributed $N(0,\sigma_{\epsilon_d}^2)$ random variable, ρ_d is a constant, and θ_i is the random variable

[8] Moffitt and Ridder (2007) present the general theory and survey applications of the 2SML methodology.

defined above. We assume that D_i equals 1 if D_i^* is greater than or equal to zero and that D_i equals 0 otherwise. The vector of household characteristics is denoted by X_{di}. The subscript d is used to indicate variables (or coefficients) related to D_i.

Let w_i^* denote the share of total non-durable expenditure during the two-week Diary Survey period going to postage *consumption* and w_i the share of total non-durable goods expenditures going to postage *expenditures* by household i for the two-week interval. Because postage expenditure during the two-week interval is observed but postage consumption is not, w_i is observed, but w_i^* is unobserved. The model for the unobserved share of postage consumption in total non-durable goods expenditure during the two-week interval is

$$\ln(w_i^*) = X'_{wi}\beta_w + \sum_{j=1}^{3}\beta_{pj}\ln\left(\frac{p_j}{M_i}\right) + \gamma C_i + \rho_w\theta_i + \epsilon_{wi}, \tag{4}$$

where ρ_w is a constant and ϵ_{wi} is an independent identically distributed $N(0, \sigma^2_{\epsilon_d})$ random variable. We denote the price of good j by p_j, where $j = 1, 2, 3$, respectively, denotes postal delivery services, telephones services, and other non-durable goods. For these prices, we use the monthly Consumer Price Indexes for postal delivery services, telephone services and non-durable goods described in Section 2.2. Total expenditure on these three non-durable goods for household i is denoted by M_i. The vector of demographic characteristics for household i is X_{wi}. The subscript w indicates variables (or coefficients) associated with w_i. This share equation can be derived from applying Roy's Identity to a homothetic translog indirect utility function in these three goods, so it is consistent with the assumption of utility-maximizing behavior at the household level.

The final equation of the model is an expression for M_i, total non-durable goods expenditure during the two-week time interval for household i. Because our data are collected for a two-week interval, observed expenditure for that time interval may be different from actual non-durable consumption. The level of non-durable expenditure in the Diary Survey may therefore depend on the same observed and unobserved heterogeneity that determines which goods, including postal delivery services, were purchased during the two week interval. For this reason, we hypothesize the following model for the logarithm of total non-durable goods expenditure:

$$\ln(M_i) = X'_{mi}\beta_m + \rho_m\theta_i + \epsilon_{mi}, \tag{5}$$

where ρ_m is a constant, ϵ_{mi} is an independent identically distributed $N(0, \sigma^2_{\epsilon_m})$ random variable, and X_{mi} contains the same vector of observable household characteristics as X_{di}. Note that θ_i enters this equation as well as the previous three Eqs. (1), (3) and (4). By doing so, we control for potential correlation between the four observed endogenous variables due to unobserved heterogeneity impacting the household's decisions about the values of each of these variables.

All of the parameters of the four-equation model are not identified because we only observe whether the household owns a computer or purchases postage during the two-week Diary Survey sample period, not the value of the underlying willingness to own a computer or purchase postage. Therefore, it is necessary to impose normalization restrictions on the parameters of the computer ownership and postage purchase equations. First, we assume that $\sigma^2_\theta + \sigma^2_{\epsilon_c} = 1$. This implies that $\beta_c^* = \beta_c$, so that all of the year-by-year probits for the probability of computer ownership yield consistent estimates of β_c for each year of the sample. The probability of computer ownership for household i conditional on θ_i is then equal to

$$\Pr(C_i = 1|\theta_i) = \Phi\left[\frac{X'_{ci}\beta_c + \theta}{\sigma_{\epsilon_c}}\right], \quad \text{where } \sigma^2_{\epsilon_c} = 1 - \sigma^2_\theta. \tag{6}$$

We also normalize that $\rho_d^2\sigma_\theta^2 + \sigma^2_{\epsilon_d} = 1$. Accordingly, the probability of purchasing postage for household i conditional on θ_i is given by

$$\Pr(D_i = 1|\theta_i) = \Phi\left[\frac{X'_{di}\beta_d + \rho_d\theta}{\sigma_{\epsilon_d}}\right], \quad \text{where } \sigma^2_{\epsilon_d} = 1 - \rho_d^2\sigma_\theta^2. \tag{7}$$

The likelihood function for our econometric model requires these two probabilities and two density functions, each of which corresponds to each of the preceding four equations. To obtain the density of total non-durable goods expenditure, we use the model given in Eq. (5). The density of total non-durable expenditures conditional on θ_i is then equal to

$$f(M_i|\theta_i) = \frac{1}{M_i\sigma_{\epsilon m}} \times \phi\left[\frac{\ln(M_i) - X'_{mi}\beta_m - \rho_m\theta_i}{\sigma_{\epsilon m}}\right]. \tag{8}$$

To derive the density function of the share of postal expenditure in total non-durable expenditure, however, we need to account for the difference between observed postage expenditure and unobserved postage consumption. Therefore, we posit that if a purchase of postage occurs in the two-week interval (i.e. $D_i = 1$), the household buys the amount equal to its unobserved consumption of postal delivery services for the two-week interval, w_i^*, multiplied by the inverse of its postage purchase probability in that period conditional on θ_i, $\frac{1}{\Pr(D_i=1|\theta_i)}$. For example, if the household's unobserved two-week demand for postal delivery services is \$10.00, and its probability of purchasing postage within any two-week interval is 0.5, this implies that when the household purchases postage it will buy $\$20.00 = \$10.00 \times \frac{1}{0.5}$ worth of postage to maintain its rate of consumption for its purchase frequency. Therefore, the relation between postage expenditure and postage consumption conditional on θ_i is given by

$$w_i = D_i \times w_i^* \times \frac{1}{\Pr(D_i = 1|\theta_i)}. \tag{9}$$

To compute the density of the observed share of postal expenditure in observed total non-durable expenditure, w_i, implied by this purchase frequency model, take the logarithm of both sides (9), and use both (4) and (7) to obtain the following relation conditional on θ_i and $D_i = 1$:

$$\epsilon_{wi} = \ln(w_i) - X'_{wi}\beta_w - \sum_{j=1}^{3}\beta_{pj}\ln\left(\frac{p_j}{M_i}\right) - \gamma C_i + \ln\left[\Phi\left(\frac{X'_{di}\beta_d + \rho_d\theta}{\sigma_{\epsilon_d}}\right)\right] - \rho_w\theta_i. \tag{10}$$

The density of the share of total non-durable goods expenditures spent on postage conditional on the value of θ_i is equal to the equation in Box I.

Because $\ln(w_i^*)$ is assumed to be normally distributed, w_i^* must therefore only take on positive values. This model assumes that all households consume a non-zero (although it can be extremely small) amount of postal delivery services within a two-week time period.

At this point we should note that there are a number of possible econometric models for the combined postage purchase and postage expenditure decision. For example, rather than assuming postal consumption is always positive, zero expenditure of postage during the two-week Diary Survey period could be modeled as result of a corner solution in the household's utility maximization problem. Specifically, at the prevailing price of postage, the household's marginal utility of the first unit of postage consumption divided by the marginal utility of total non-durable expenditure is less than the price of postage. Wolak (1997) estimates four different econometric models (including

$$f(w_i|\theta_i, C_i) = \frac{1}{w_i\sigma_{\epsilon_w}} \times \phi\left[\frac{\ln(w_i) - X'_{wi}\beta_w - \sum_{j=1}^{3}\beta_{pj}\ln\left(\frac{p_j}{M_i}\right) - \gamma C_i + \ln\left[\Phi\left(\frac{X'_{di}\beta_d+\rho_d\theta}{\sigma_{\epsilon_d}}\right)\right] - \rho_w\theta_i}{\sigma_{\epsilon_w}}\right]$$

where $\phi(\cdot)$ is the standard normal density

Box I.

this corner solution model) that account for the distinction between purchase and consumption of postal delivery services using CEX data for the 1986–1994 time period. All of these models yield likelihood functions for the same observed endogenous variables — postal delivery services expenditure and the binary postage purchase decision. Wolak (1997) uses likelihood-based non-nested hypothesis tests derived by Vuong (1989) to determine whether any of the four models provides a statistically significantly higher average value for the logarithm of the likelihood function. The infrequency of purchase model with non-zero consumption of postal delivery services, a simplified version of our four-equation model, was found by Wolak (1997) to provide an overwhelmingly statistically significantly superior description of these observed endogenous variables relative to each of the three competing models. Wolak (1997) also presented results from counterfactual simulation using each of the four models and found that those obtained from the infrequency of purchase with nonzero consumption model were the most plausible. These results provide strong empirical support for our model of the infrequency of postage purchase and postage consumption relative to the three competitors described in Wolak (1997).

The likelihood function conditional on θ_i is composed of two possible events: (i) the household purchases postage and (ii) the household does not purchase postage. In each case we do not know whether the household has a computer, so we incorporate the probability of computer ownership estimated from the Interview Survey sample each year into our econometric model. This process yields the complete likelihood function conditional on θ. We then integrate with respect to the density of θ to obtain the unconditional likelihood for our Diary Survey sample. We maximize this unconditional likelihood to compute estimates of $\Delta = (\beta_p, \beta_w, \beta_d, \beta_m, \rho_w, \rho_d, \rho_m, \sigma^2_{\epsilon_w}, \sigma^2_{\epsilon_m})$ given the values of β_c estimated from household-level computer ownership probits applied to the Interview Survey sample for each year from 1988 to 2004.

Because θ_i is an independent identically distributed $N(0, \sigma^2_\theta)$ random variable, its density is given by $\frac{1}{\sigma_\theta}\phi(\frac{\theta_i}{\sigma_\theta})$. In terms of the notation above, the likelihood function for observation i becomes:

$$\begin{aligned} L_i(\Delta) = \int_{-\infty}^{\infty} & [\Pr(D_i = 1|\theta_i) \times \{\Pr(C_i = 1|\theta_i) f(w_i|\theta_i, C_i = 1) \\ & + \Pr(C_i = 0|\theta_i) f(w_i|\theta_i, C_i = 0)\}]^{D_i} \\ & \times [\Pr(D_i = 0|\theta_i)]^{1-D_i} \times f(M_i|\theta_i) \times \frac{1}{\sigma_\theta}\phi\left(\frac{\theta_i}{\sigma_\theta}\right) d\theta. \quad (11) \end{aligned}$$

There is a variety of potential ways to compute the integral with respect to the density of θ necessary to evaluate this likelihood function. We could compute (11) by a univariate numerical integration with respect to θ. Another approach is simulated maximum likelihood. In this case we simulate B independent identically distributed $N(0, 1)$ random variables for each observation. Let Z_b denote the value of this $N(0, 1)$ random variable for draw b. We then substitute $Z_b \times \sigma_\theta$ for θ_b and compute the average value of the conditional likelihood for these B values of θ_b.

In terms of the notation above, the simulated likelihood function value for a household where a purchase of postage takes place, $D_i = 1$, and the expenditure level, w_i, is observed, and is equal to the equation in Box II.

The simulated likelihood function value where no purchase of postage takes place is equal to:

$$\begin{aligned} & \frac{1}{B}\sum_{b=1}^{B}\left(1 - \Phi\left[\frac{X'_{di}\beta_d + \rho_d Z_b\sigma_\theta}{\sqrt{1-\rho_d^2\sigma_\theta^2}}\right]\right) \times \frac{1}{M_i\sigma_{\epsilon_m}} \\ & \times \phi\left[\frac{\ln(M_i) - X'_{mi}\beta_m - \rho_m Z_b\sigma_\theta}{\sigma_{\epsilon_m}}\right]. \quad (12) \end{aligned}$$

To estimate the model, we used a value of $B = 20$. Experiments with larger values did not appreciably change the estimation results but did significantly increase computation time.

3.3. Variables entering demand and purchase probability functions

Consumer theory provides clear guidance as to what variables should enter Eq. (4). Because this is the demand function of the logarithm of postage consumption, it follows that the logarithm of the own-price, the prices of other goods consumed by the household, and total non-durable expenditures should enter Eq. (4). Because of our desire to understand how computer ownership impacts postage consumption, we enter C_i in this equation as well. We also enter demographic variables describing the characteristics of the household which should account for differences in the consumption of postal delivery services. For this reason, X_{wi} includes race, number of children, marital status, education, occupation, and age of the head.

Economic theory, however, provides less guidance for what variables should enter Eq. (3). There are a number of reasons why the probability of purchasing postage should differ across households. A major determinant of these differences is the opportunity cost to the household of making a purchase. If it were costly to purchase postage, then all household would purchase only when at least one household member actually consumed postal delivery services. Consequently, we expect household characteristics that predict the opportunity cost of purchasing postage to be important predictors of this probability. As a result, X_{di} includes the geographic area where the household resides, the number of children in the household, the marital status of the head, the education of the spouse and head, the occupation, age, hours of work of the head and spouse, and household income. Table 4 presents summary statistics of these variables. The definitions of the variables are given in Table 5.

Note that the range of real (in January 1986 dollars) total non-durable goods expenditure in the two-week period in our sample is \$0.49–\$23,612. As a result, there is considerable amount of variability across households in the share of total expenditure going to postal delivery services. Because of the concern that measurement or recording errors could result in some very large values of total non-durable goods expenditures in our sample, we perform our analysis on a restricted sample of households selected to have less than \$5000 of total non-durable expenditures during the two-week period. This reduced our sample size by 0.5% (605 observations out of 112,120).

$$\frac{1}{B}\sum_{b=1}^{B}\Phi\left[\frac{X'_{di}\beta_d+\rho_d Z_b\sigma_\theta}{\sqrt{1-\rho_d^2\sigma_\theta^2}}\right]\times\left\{\Phi\left[\frac{X'_{ci}\beta_c+Z_b\sigma_\theta}{\sqrt{1-\sigma_\theta^2}}\right]\times\frac{1}{w_i\sigma_{\epsilon_w}}\right.$$

$$\times\phi\left[\frac{\ln(w_i)-X'_{wi}\beta_w-\sum_{j=1}^{3}\beta_{pj}\ln\left(\frac{p_j}{M_i}\right)-\gamma+\ln\left[\Phi\left(\frac{X'_{di}\beta_d+\rho_d Z_b\sigma_\theta}{\sigma_{\epsilon_d}}\right)\right]-\rho_w Z_b\sigma_\theta}{\sigma_{\epsilon_w}}\right]+\left(1-\Phi\left[\frac{X'_{ci}\beta_c+Z_b\sigma_\theta}{\sqrt{1-\sigma_\theta^2}}\right]\right)\times\frac{1}{w_i\sigma_{\epsilon_w}}$$

$$\left.\times\ \phi\left[\frac{\ln(w_i)-X'_{wi}\beta_w-\sum_{j=1}^{3}\beta_{pj}\ln\left(\frac{p_j}{M_i}\right)+\ln\left[\Phi\left(\frac{X'_{di}\beta_d+\rho_d Z_b\sigma_\theta}{\sigma_{\epsilon_d}}\right)\right]-\rho_w Z_b\sigma_\theta}{\sigma_{\epsilon_w}}\right]\right\}\frac{1}{M_i\sigma_{\epsilon_m}}\times\phi\left[\frac{\ln(M_i)-X'_{mi}\beta_m-\rho_m Z_b\sigma_\theta}{\sigma_{\epsilon_m}}\right]$$

Box II.

Table 4
Consumer Expenditure Diary Survey summary statistics

Variable	Mean	S.D.	Min	Max
Postage purchase indicator	0.269	0.443	0.000	1.000
Postage expenditure	2.710	9.269	0.000	708.820
Telephone expenditure	26.913	54.220	0.000	1,597.587
Nondurable expenditure	526.301	514.727	0.490	23,611.523
#postage purchases (in 2 weeks)	0.357	0.708	0.000	23.000
Postage expn. share	0.006	0.021	0.000	1.000
Telephone expn. share	0.047	0.087	0.000	1.000
Nondurables price (Jan 1986 = 1)	1.325	0.189	0.961	1.652
Telepone price (Jan 1986 = 1)	0.959	0.035	0.888	1.016
Postage price (Jan 1986 = 1)	1.391	0.227	1.000	1.732
Computer ownership prob.	0.399	0.303	0.000	1.000
Northeast	0.189	0.391	0.000	1.000
Midwest	0.238	0.426	0.000	1.000
South	0.289	0.453	0.000	1.000
West	0.231	0.421	0.000	1.000
smsa	0.829	0.377	0.000	1.000
home.owner	0.657	0.475	0.000	1.000
Renter	0.318	0.466	0.000	1.000
dorm.resident	0.008	0.092	0.000	1.000
family.size	2.591	1.499	1.000	24.000
pers.lt.18	0.719	1.124	0.000	12.000
pers.gt.64	0.301	0.607	0.000	5.000
#earner	1.408	0.990	0.000	9.000
#vehicles	1.691	1.199	0.000	63.000
White	0.889	0.315	0.000	1.000
Black	0.101	0.301	0.000	1.000
Male	0.588	0.492	0.000	1.000
Married	0.568	0.495	0.000	1.000
hs.grad	0.299	0.458	0.000	1.000
less.college	0.216	0.411	0.000	1.000
college.grad	0.310	0.462	0.000	1.000
Age	0.474	0.173	0.140	0.940
Age^2	0.255	0.180	0.020	0.884
spouse.age	0.255	0.255	0.000	0.940
spouse.age^2	0.130	0.162	0.000	0.884
prof.occupation	0.324	0.468	0.000	1.000
tech.occupation	0.188	0.391	0.000	1.000
self.employed	0.082	0.274	0.000	1.000
Retired	0.114	0.317	0.000	1.000
work.hours	30.531	20.861	0.000	99.000
spouse.work.hours	15.010	20.263	0.000	98.000
positive.income (in $10,000)	3.351	3.921	0.000	90.893
negative.income (dummy)	0.138	0.344	0.000	1.000
December (dummy)	0.111	0.314	0.000	1.000

The number of observations is 112,120.

4. Estimation results and welfare impact

Table 6 presents estimates of the parameters of our model. The price coefficients are estimated precisely, as are most of the coefficients on the demographic variables. The household demographic variables significantly improve the predictive power of the model, indicating the presence of deterministic differences in postage consumption and frequency of purchase across

Table 5
Definition of variables

Northeast	1 if household resides in Northeast Census region
Midwest	1 if household resides in Midwest Census region
South	1 if household resides in Census Southern region
West	1 if household resides in Census Western region
smsa	1 if household resides in Metropolitan Statistical Area
home.owner	1 if household owns house
Renter	1 if household rents house
dorm.resident	1 if household is living in college dormitory
Age	Age of reference person in the household
spouse.age	Age of spouse of reference person
White	1 if reference person is white
Black	1 if black
Male	1 if male
Married	1 if married
hs.grad	1 if highest education is high school graduate
less.college	1 if some college, less than college
college.grad	1 if college graduate
prof.occupation	1 if the job best fits the category of professional
tech.occupation	1 if the job best fits the category of technician
self.employed	1 if reference person is self-employed
Retired	1 if reference person is retired
family.size	The number of members in the household
pers.lt.18	The number of persons younger than 18
pers.gt.64	The number of persons older than 64
#earner	The number of earners
#vehicles	The number of vehicles
work.hours	The number of hours in a week that reference person worked
spouse.work.hours	The number of hours in a week that spouse worked (if applicable)
positive.income	Real final income before tax (in $10,000) if >0
negative.income	1 if household income, before tax, is negative
December	1 if survey month is December
year.after.1993	1 if survey year is between 1994 and 2004
year.after.2000	1 if survey year is between 2001 and 2004

households based on these observable characteristics. Table 6 also presents estimates of the elements of the covariance matrix of the errors to the four-equation model. Most of the covariances between the unobservables in each equation are precisely estimated, which signals the importance of accounting for the correlation between the endogenous variables of our economic model of computer ownership, postal consumption, postal purchases, and total non-durable expenditure to obtain consistent estimates of the parameters of this four-equation model.

Table 8 gives the household-level elasticities of postage demand with respect to the prices of postage, telephone services, other non-durable goods, and total non-durable expenditure. The structure of the postage demand model in Eq. (4) implies that these elasticities and the elasticity with respect to computer ownership do not vary across households. Because the range of activities that can be performed using a computer changed dramatically as the growth of the Internet exploded during the mid-1990s, we would expect the impact of computer ownership on postage consumption to change over time. For this reason, we have interacted the unobserved computer ownership indicator variable with two indicator variables: year.after.1993 that is one for all Diary Survey households in the years after 1993 and zero otherwise; year.after.2000 that is one for all Diary Survey households in the years after 2000 and zero otherwise. Because the World Wide Web popularized the Internet particularly after the introduction of Mosaic web browser in 1993, we use year.after.1993 to reflect the general impact of the Internet. We additionally use year.after.2000 to reflect the impact of the recent growth of the Internet on postage consumption. In this way, we allow for differences in how computer ownership impacts postage demand in different periods.

The postage demand elasticity with respect to computer ownership was positive but statistically indistinguishable from zero during the pre-1994 time period. This is consistent with the view that computer ownership during this time period offered limited opportunities for electronic substitution at the household level. In contrast, during the period 1994–2000 when household-level computer and Internet adoption exploded because of the availability of web browsers and search engines, this elasticity is −0.229 and very precisely estimated. This estimate implies that computer ownership by a household during this time period reduced its postage consumption by 22.9%. The elasticity for the period after 2000 is still negative but roughly half the size of the coefficient during the 1994–2000 period, suggesting that more recent computer adoption reduces postage consumption by less. This may also reflect the recent growth of online transactions between individual consumers, such as eBay, which require consumers to ship their goods using postal delivery services. Another explanation consistent with these estimates is that during the 1990s, most computer owners tended to be households with younger and more educated heads that are presumably more likely to use computers and the Internet to substitute for the full-range of postal services. Later adopters of personal computers, however, include more consumers who are older and less technologically sophisticated consumers, and therefore are likely to use their computers to substitute for fewer traditional postal delivery services.

A surprising result to emerge from this model is the large own-price elasticity of postal demand. This is larger in absolute value than the value presented in Wolak (1997). This elasticity is very precisely estimated and the magnitude is robust to a number of changes in the specification of our postal delivery services demand function. The estimated cross-price elasticity of postal demand with respect to the price of telephone services also increased by an order of magnitude relative to numbers reported in Wolak (1997). These own-price and cross-prices elasticities imply significant reductions in USPS revenue obtained from US households as a result of price increases for postage and price decreases for telephone services. In general, a X% price increase of a product with an own-price elasticity of ε increases total revenue from the sale of that product by $X(1+\varepsilon)$. Consequently, if the absolute value of ε is less than one – the product is inelastically demanded – total revenue will increase as a result of this price increase. A natural question to ask is: how much revenue is lost from reductions in the household-level use of postal delivery services by recent postal price increases?

Using the own-price elasticity estimates, this calculation implies that a 5% price increase yields a 3.24% reduction in postal revenue obtained from the household sector. From Table 2A, the estimated aggregate annual expenditure by the household sector on postage in 2004 was $8.28 billion. This implies a $268 million reduction in 2004 annual expenditures on postage by the household sector as a result of a 5% postage price increase. For the case of the price of telephone services, our estimates imply that a 1% decrease in the price of telephone services reduces total postal service revenues by 0.85%.

To assess the relative impact of annual personal computing technology adoption on total USPS revenue collected from the household sector, we must make some assumption about the extent to which the penetration of personal computing technology among households will increase over the course of a typical year. From 1994 to 2000, the continuously compounded annual percent increase in the fraction of US households with personal computers was 13%. Assuming this annual percent increase in personal computer penetration and using the elasticity estimate reported in Table 8 for the post-1994 time period implies a 2.8% reduction in annual USPS revenue from the household sector, or about $176 million in 2000.

Because we have estimated a demand function that is consistent with the assumption of household-level utility maximizing behavior, it is possible to compute an estimate of the

Table 6
Parameter estimates for model

Variable	Postage share equation		Postage purchase equation		Total nondurable expenditure equation	
	Para.	Estimate	Para.	Estimate	Para.	Estimate
	A. Price coefficients					
postage.price	β_{p1}	−0.647 (0.165)				
telephone.price	β_{p2}	0.848 (0.075)				
nondurable.price	β_{p3}	0.498 (0.186)				
	B. Household characteristic coefficients					
Computer	γ	0.152 (0.086)				
Computer × year.after.1993	γ_{1994}	−0.382 (0.074)				
Computer × year.after.2000	γ_{2001}	0.138 (0.043)				
Constant	β_{w0}	−7.620 (0.102)	β_{d0}	−1.021 (0.052)	β_{m0}	4.427 (0.029)
Northeast	β_{w1}	0.024 (0.040)	β_{d1}	−0.064 (0.023)	β_{m1}	−0.040 (0.014)
Midwest	β_{w2}	−0.019 (0.041)	β_{d2}	−0.061 (0.023)	β_{m2}	−0.045 (0.013)
South	β_{w3}	−0.091 (0.039)	β_{d3}	−0.122 (0.022)	β_{m3}	−0.058 (0.013)
West[a]	β_{w4}	0.006 (0.039)	β_{d4}	−0.117 (0.023)	β_{m4}	−0.088 (0.014)
smsa	β_{w5}	0.186 (0.025)	β_{d5}	0.071 (0.013)	β_{m5}	0.094 (0.007)
family.size	β_{w6}	0.002 (0.017)	β_{d6}	−0.011 (0.009)	β_{m6}	0.152 (0.005)
pers.lt.18	β_{w7}	−0.051 (0.018)	β_{d7}	0.001 (0.010)	β_{m7}	−0.052 (0.005)
pers.gt.64	β_{w8}	−0.012 (0.019)	β_{d8}	−0.039 (0.011)	β_{m8}	−0.067 (0.006)
#earners	β_{w9}	0.006 (0.016)	β_{d9}	0.051 (0.009)	β_{m9}	0.049 (0.005)
White	β_{w10}	0.109 (0.076)	β_{d10}	0.109 (0.040)	β_{m10}	0.046 (0.022)
Black	β_{w11}	−0.197 (0.081)	β_{d11}	−0.023 (0.042)	β_{m11}	−0.152 (0.023)
Male	β_{w12}	−0.185 (0.018)	β_{d12}	−0.109 (0.010)	β_{m12}	−0.044 (0.005)
Married	β_{w13}	0.444 (0.045)	β_{d13}	0.226 (0.024)	β_{m13}	0.096 (0.013)
hs.grad	β_{w14}	0.356 (0.025)	β_{d14}	0.197 (0.013)	β_{m14}	0.170 (0.007)
less.college	β_{w15}	0.460 (0.027)	β_{d15}	0.252 (0.014)	β_{m15}	0.237 (0.007)
college.grad	β_{w16}	0.639 (0.028)	β_{d16}	0.340 (0.014)	β_{m16}	0.321 (0.008)
Age	β_{w17}	1.852 (0.073)	β_{d17}	0.735 (0.038)	β_{m17}	0.403 (0.019)
spouse.age	β_{w18}	−0.115 (0.079)	β_{d18}	0.131 (0.043)	β_{m18}	0.421 (0.023)
prof.occupation	β_{w19}	0.160 (0.027)	β_{d19}	0.103 (0.014)	β_{m19}	0.037 (0.008)
tech.occupation	β_{w20}	0.097 (0.028)	β_{d20}	0.072 (0.014)	β_{m20}	0.005 (0.008)
self.employed	β_{w21}	0.085 (0.035)	β_{d21}	−0.025 (0.018)	β_{m21}	0.051 (0.010)
Retired	β_{w22}	−0.041 (0.030)	β_{d22}	0.026 (0.016)	β_{m22}	0.043 (0.009)
work.hours	β_{w23}	−0.002 (0.001)	β_{d23}	−0.002 (0.000)	β_{m23}	0.003 (0.000)
spouse.work.hours	β_{w24}	−0.001 (0.001)	β_{d24}	−0.003 (0.000)	β_{m24}	0.000 (0.000)
positive.income	β_{w25}	0.023 (0.003)	β_{d25}	0.010 (0.001)	β_{m25}	0.047 (0.001)
negative.income (dummy)	β_{w26}	−0.132 (0.028)	β_{d26}	−0.228 (0.014)	β_{m26}	−0.072 (0.007)
december	β_{w27}	0.430 (0.022)	β_{d27}	0.087 (0.013)	β_{m27}	−0.017 (0.007)
positive.income × year.2004	β_{w28}	−0.005 (0.005)	β_{d28}	−0.001 (0.003)	β_{m28}	−0.014 (0.002)
negative.income × year.2004	β_{w29}	0.363 (1.006)	β_{d29}	0.212 (0.255)	β_{m29}	0.500 (0.146)
	C. Year dummy coefficients					
year.1987			β_{d1987}	−0.020 (0.018)	β_{m1987}	0.053 (0.014)
year.1988			β_{d1988}	−0.028 (0.019)	β_{m1988}	0.061 (0.015)
year.1989			β_{d1989}	−0.081 (0.019)	β_{m1989}	0.134 (0.015)
year.1990			β_{d1990}	−0.041 (0.021)	β_{m1990}	0.140 (0.014)
year.1991			β_{d1991}	−0.230 (0.020)	β_{m1991}	0.216 (0.014)
year.1992			β_{d1992}	−0.272 (0.020)	β_{m1992}	0.240 (0.014)
year.1993			β_{d1993}	−0.408 (0.021)	β_{m1993}	0.211 (0.014)
year.1994			β_{d1994}	−0.422 (0.021)	β_{m1994}	0.225 (0.015)
year.1995			β_{d1995}	−0.467 (0.023)	β_{m1995}	0.247 (0.016)
year.1996			β_{d1996}	−0.467 (0.022)	β_{m1996}	0.274 (0.015)
year.1997			β_{d1997}	−0.496 (0.022)	β_{m1997}	0.250 (0.015)
year.1998			β_{d1998}	−0.482 (0.022)	β_{m1998}	0.258 (0.014)
year.1999			β_{d1999}	−0.500 (0.021)	β_{m1999}	0.279 (0.013)
year.2000			β_{d2000}	−0.518 (0.022)	β_{m2000}	0.331 (0.013)
year.2001			β_{d2001}	−0.493 (0.021)	β_{m2001}	0.380 (0.014)
year.2002			β_{d2002}	−0.553 (0.021)	β_{m2002}	0.382 (0.014)
year.2003			β_{d2003}	−0.582 (0.022)	β_{m2003}	0.390 (0.014)
year.2004			β_{d2004}	−0.611 (0.028)	β_{m2004}	0.463 (0.017)
	D. Covariance matrix coefficients					
	σ_θ	0.879 (0.148)				
	σ_{ϵ_w}	0.969 (0.004)			σ_{ϵ_m}	0.707 (0.002)
	ρ_w	−0.691 (0.124)	ρ_d	−0.638 (0.108)	ρ_m	−0.336 (0.057)

Standard errors in parentheses. The table reports the parameter estimates from simulated maximum likelihood estimation using the restricted sample in the 1986–2004 CEX data. The restricted sample consists of households that had less than $5000 of total non-durable expenditures during the two-week period. The number of observations is 111,515. Standard errors are computed using the BHHH method.

[a] For approximately 13% of households, the information on the region is suppressed because of confidentiality concerns. We treat them as living in a different region and include all four dummies for the region.

household-level welfare impact of a given increase in the price of postage. Specifically, let $V(p^0, M^0, A, C, \epsilon)$ equal the indirect utility function of a household at price vector p^0, with total non-durable expenditure M^0, the vector of observable characteristics A, unobservable computer ownership status C, and the vector of unobservable household characteristics ϵ. Using this indirect utility

Table 7
Estimated covariance matrix of composite errors

	Computer ownership equation	Postage purchase equation	Postage share equation	Total expenditure equation
Computer ownership	1	−0.493 (0.083)	−0.534 (0.090)	−0.260 (0.044)
Postage purchase		1	0.341 (0.018)	0.166 (0.003)
Postage share			1.309 (0.033)	0.180 (0.008)
Total expenditure				0.587 (0.002)

Standard errors in parentheses. See Appendix for the formulas. Standard errors are computed using the BHHH method.

Table 8
Elasticities of postage consumption

Elasticity of postage consumption with respect to	Value
Postage price	−1.6474 (0.1650)
Telephone price	0.8477 (0.0749)
Nondurable price	0.4975 (0.1861)
Nondurable expenditure	0.3022 (0.0121)
Computer owernship	0.1520 (0.0863)
Computer ownership between 1994 and 2000	−0.2295 (0.0468)
Computer ownership between 2001 and 2004	−0.0915 (0.0433)

Standard errors in parentheses.

function, we can compute an estimate of the amount of additional expenditure necessary to keep the household at the initial level of welfare at a higher price for postage. Let p^1 denote the new vector of prices with a 5% increase in the price of postage but with all other prices at the same values as the initial vector p^0. We compute the compensating variation associated with this price change as the solution in CV to the following equation:

$$\begin{aligned}\Phi\left[\frac{X_c'\hat{\beta}_c+\theta}{\sqrt{1-\hat{\sigma}_\theta^2}}\right]\times V(p^1,M^0+CV,A,C=1,\epsilon)\\ +\left(1-\Phi\left[\frac{X_c'\hat{\beta}_c+\theta}{\sqrt{1-\hat{\sigma}_\theta^2}}\right]\right)\times V(p^1,M^0+CV,A,C=0,\epsilon)\\ =\Phi\left[\frac{X_c'\hat{\beta}_c+\theta}{\sqrt{1-\hat{\sigma}_\theta^2}}\right]\times V(p^0,M^0,A,C=1,\epsilon)\\ +\left(1-\Phi\left[\frac{X_c'\hat{\beta}_c+\theta}{\sqrt{1-\hat{\sigma}_\theta^2}}\right]\right)\times V(p^0,M^0,A,C=0,\epsilon). \qquad (13)\end{aligned}$$

Because a household's computer ownership status is unobservable, we assume that each household's indirect utility function is the product of the probability that it owns a computer times its indirect utility function if it owns a computer plus the product of the probability that it does not own a computer times its indirect utility function if it does not own a computer. We can compute the value of CV for each household in our sample associated with a 5% increase in the price of postage. Moreover, using the sampling weights for the consumer diary survey, we can also compute an estimate of population welfare loss associated with this price increase. Table 9 gives the mean value of this compensating variation for the two-week sample period of $0.126 for all households in 2001–2004 sample. The sample mean of the ratio of CV to the dollar amount of postage the household is predicted to consume in during the two-week sample period is 0.05. The annual aggregate welfare loss to all US households in 2001–2004 associated with this price increase is $333 million.

Table 9
Compensating variation and other measures for a 5% price increase for 2001–2004 sample

Welfare measures	Value
Mean compensating variation for entire sample of households for 2-week samples period	$0.1263 (0.0842)
$\frac{\text{(mean compensating variation)}}{\text{(new price}\times\text{postage)}}$ for entire sample of households for 2-week sample period	0.0496 (2.29E−06)
$\frac{\text{(mean compensating variation)}}{\text{(nondurable expenditure)}}$ for entire sample of households for 2-week sample period	0.0003 (0.0003)
Estimated aggregate compensating variation for all households in 2001–2004 on annual basis	$333 million
Revenue decrease for 2001–2004 for all households in 2001–2004 on annual basis	$215 million

Standard deviation in parentheses. All the measures are calculated by using 2001–2004 CEX samples.

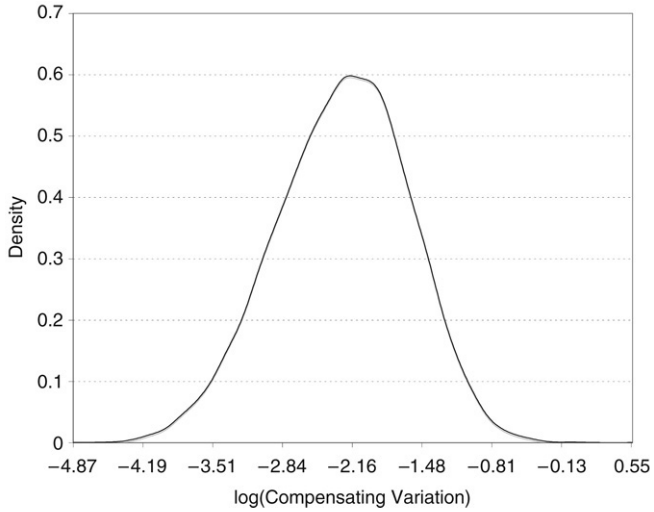

Fig. 4. Kernel density estimate of log(CV).

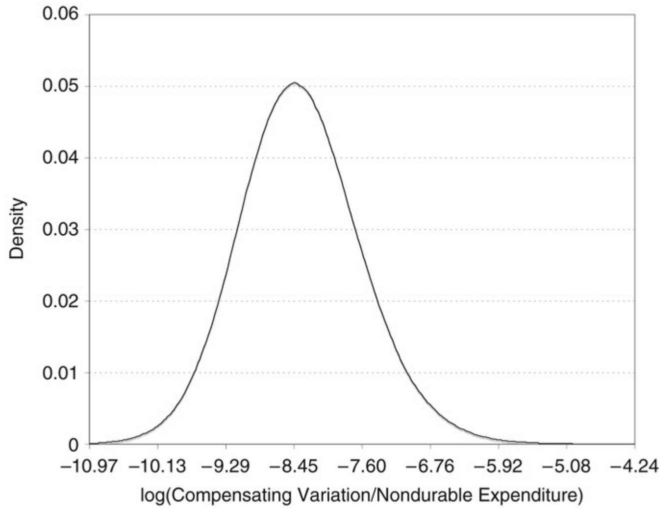

Fig. 5. Kernel density estimate of log(CV/M).

There are estimated to be 107 million households in the US in 2004. This implies that US households must be compensated an average of $3.11/household on an annual basis to be indifferent to this postal price increase.

Figs. 4 and 5 are histograms of the household-level values of the logarithm of compensating variation and the logarithm of the ratio of compensating variation to total non-durable expenditure

Table 10
Compensating variation regressions

Variable	Dependent variable	
	log(CV) Estimate	log(CV/M) Estimate
Constant	−4.3650 (0.0176)	−9.2517 (0.0350)
Northeast	0.1219 (0.0050)	0.0973 (0.0099)
Midwest	0.0732 (0.0043)	0.0781 (0.0087)
West	0.0882 (0.0045)	0.1228 (0.0090)
smsa	0.2062 (0.0046)	0.1455 (0.0092)
family.size	0.0451 (0.0036)	−0.1120 (0.0071)
pers.lt.18	−0.0597 (0.0039)	−0.0222 (0.0077)
pers.gt.64	−0.0285 (0.0044)	0.0505 (0.0090)
#earners	0.0226 (0.0037)	−0.0347 (0.0073)
White	0.0975 (0.0135)	0.1036 (0.0265)
Black	−0.2488 (0.0144)	−0.0771 (0.0286)
Male	−0.2015 (0.0036)	−0.1420 (0.0073)
Married	0.4660 (0.0100)	0.4094 (0.0201)
hs.grad	0.3865 (0.0056)	0.2495 (0.0112)
less.college	0.5004 (0.0060)	0.2735 (0.0121)
college.grad	0.6976 (0.0059)	0.3917 (0.0117)
Age	2.0040 (0.0159)	1.5958 (0.0321)
spouse.age	−0.0088 (0.0180)	−0.4571 (0.0358)
prof.occupation	0.1685 (0.0052)	0.1120 (0.0104)
tech.occupation	0.0889 (0.0051)	0.0686 (0.0102)
self.employed	0.1067 (0.0071)	0.0295 (0.0140)
Retired	−0.0212 (0.0075)	−0.1040 (0.0153)
work.hours	−0.0010 (0.0001)	−0.0032 (0.0003)
spouse.work.hours	−0.0016 (0.0001)	−0.0010 (0.0003)
positive.income	0.0325 (0.0006)	−0.0012 (0.0012)
negative.income (dummy)	−0.1664 (0.0059)	−0.0650 (0.0121)
positive.income × year.2004	−0.0052 (0.0009)	−0.0051 (0.0017)
negative.income × year.2004	0.4858 (0.0545)	−0.0269 (0.1040)
December	0.4218 (0.0063)	0.3828 (0.0128)
year.2002	−0.0339 (0.0046)	−0.0426 (0.0091)
year.2003	−0.0633 (0.0046)	−0.0792 (0.0092)
year.2004	−0.0627 (0.0069)	−0.0907 (0.0137)

Standard errors in parentheses. Standard errors are constructed using the covariance matrix given in White (1980). The 2001–2004 CEX samples are used. The number of observations is 28,610.

for all households in our sample. We apply a logarithmic transformation to both CV and CV/M because the distribution of these magnitudes are extremely positively skewed. These figures show that there is a considerable amount of heterogeneity in the value of CV measured in dollars or as fraction of total non-durable expenditure across US households. In order to understand what observable household characteristics predict large values of ln(CV) and ln(CV/M), Table 10 reports estimated best linear predictor functions of these magnitudes for our sample estimates. Because we interpret these regressions as simply best linear predictors for the true nonlinear relationship between CV and ln(CV/M) and the observable demographic characteristics of each household, we report the standard error estimates recommended in White (1980). The results in the first column show that higher income households experience larger absolute welfare losses (greater values of ln(CV)), whereas they experience lower welfare losses relative to the level of total non-durable goods expenditures (lower values of ln(CV/M)). Among the various occupations, households with heads that are professional workers experience the greatest absolute and relative welfare losses. In terms of education levels, households with heads that have higher education levels experience greater welfare losses. Households with white heads experience greater absolute and relative welfare losses relative to all other households. Households living in urban areas experience greater absolute and relative welfare losses. Married households also experience greater absolute and relative welfare losses than single headed households. Finally, households with retired heads and more members 64 years or older experience greater absolute and relative welfare losses. Household with both older heads and older spouses of the head experience greater absolute and relative welfare losses.

These results on the distribution of welfare losses seem consistent with the view that computer ownership exerts a differential impact on the household-level demand for USPS services. As noted above, we expect older households to be less likely to purchase a computer and use it to replace as many of the services provided by the USPS than a household with a younger head and spouse. The same should be true for households with more members 64 years old or older. Finally, the impact on higher educated households and those with professional heads seem to indicate that these households use postal delivery services more intensively than other households, controlling for all other observable characteristics.

5. Conclusions and policy implications of research

Our estimation results are not encouraging for the future financial viability of the USPS. Our model predicts that recent trends in postage rate increases, the growing penetration of personal computing technology, and the declining cost of telephone services will all reduce the amount of revenue the USPS will receive from US households in the future. Unless the demand for USPS services from other segments of the economy picks up this slack, the USPS is likely to experience revenue reductions in the future even with significant rate increases.

The own-price elasticity estimates from our model indicate that rate increases are likely to significantly reduce USPS revenue from the household sector at an even greater rate than the results reported in Wolak (1997). Moreover, these large own-price and cross-price elasticity estimates are even more precisely estimated than those reported in Wolak (1997). The impact of computer ownership is also much more precisely estimated and larger in absolute value than the results reported in Wolak (1997) for the period of rapid expansion of Internet usage by computer users from 1994 to 2000. These estimation results predict revenue reductions from the US household sector from future postal rate increases, telephone services price reductions, and adoption of personal computing technology by US households, although the computer ownership elasticity for the post-2000 period implies that future computer adoption at the household level will not lead to as large revenue reductions as large as those associated with the adoptions that occurred during the period 1994–2000.

Our analysis of the welfare impact shows that postal rate increases impose greater burdens on older, higher-educated households located in urban areas. Although the absolute burden is greater for higher income households, the relative burden is lower. In terms of relative impact, the age of the head of household is a major determinant of the magnitude of both the absolute magnitude of ln(CV) and the value of ln(CV/M). Households located in the South Census region appear to suffer less harm than households located in the Northeast, Midwest, or West census regions. In summary, the absolute and relative welfare losses associated with postal rate increases tend to be distributed among US households according to observable demographic characteristics in a manner consistent with our demand estimates.

Clearly, there are many caveats associated with these results. One obvious direction for future research is to investigate alternative functional forms for both the demand for postal delivery services and the frequency of purchase model. As noted above, we experimented with a large number of more flexible functional forms involving squares and cross-products of the logarithms of the prices of postage, telephone services and non-durable goods, and total non-durable expenditures and obtain similar values for the sample means of the household-level elasticities. Nevertheless, there are other directions worth exploring to determine the robustness of these estimation results, given their dire predictions about the future demand for USPS services from US households.

We now explore the implications of these results for future postal policymaking. First, operating statistics from the USPS show trends that are consistent with our estimation results. According to USPS Revenue, Pieces, and Weight Reports available from the USPS website, the volume of single piece First-Class mail has declined every year from 2000 to 2006 at an average annual rate of close to 4% per year. A substantial fraction of the postage expenditure by the household sector is for single piece First-Class mail, so this steady and significant decline in single piece First-Class mail volume is broadly consistent with our estimation results.

Despite this precipitous decline in single-piece First Class mail volume from 2000 to 2006, total First-Class Mail volume has fallen at approximately 1% per year over this same time period because of a steady increase in the volume of Presorted First-Class Mail. Presorted First-Class Mail is used by businesses to send bills and other time-sensitive or confidential communications to their customers. The opportunities for businesses to substitute away from this mode of billing customers are limited by the willingness of these customers to receive bills electronically. Businesses also do not have the option to use less expensive USPS delivery services besides First-Class Mail to send bills to their customers. By law, businesses are required to use First-Class Mail to send confidential billing information to their customers. Consequently, it is very unlikely that a credit card company, public utility, or other business that invoices its customers on a monthly basis can completely eliminate its use of Presorted First-Class Mail to send bills to a significant fraction of its customers for the foreseeable future. Consequently, it seems reasonable to assume that Presorted First-Class Mail volume will continue to increase with the growth in aggregate economic activity, as the volume of business-to-consumer billing communications increases, although some of this growth will be mitigated by electronic substitution to online invoicing and bill-paying by the business and its customers.

So how has the USPS remained financially viable in the face of these volume declines in First-Class Mail? Postal price increases have helped to stem the implied revenue loss. Since January 1, 2000 to the present, there have been three separate postal price increases (on January 7, 2001, June 30, 2002, and January 8, 2006). According to our own-price elasticity estimates, the USPS revenue increases from these postal price increases have come primarily from the business sector which is very likely to have an inelastic demand for First-Class mail for the reasons noted above. A major factor in maintaining the financial viability of the USPS during the past six years is rapid growth in the volume of Standard Mail. This service is available for mailers to use for advertisements and merchandise that are not required by law to be sent by First-Class mail. According to the USPS, Standard Mail is "typically used for bulk advertising to multiple delivery addresses" (United States Postal Service, 2007). In 2006, Standard Mail surpassed First Class Mail as having the largest volume of any class of mail. During 2006, 102.4 billion Standard Mail pieces were delivered versus 97.6 billion First-Class Mail pieces (United States Postal Service, 2007). However, the USPS obtained slightly less than one-half of the revenue per piece delivered from Standard Mail relative to First-Class Mail in 2006. Despite this price differential, the rapidly increasing volume of Standard Mail and declining volume of First-Class Mail has led to an increasing revenue share for Standard Mail. From 2002 to 2006, the revenue share of Standard Mail in total USPS mail revenue has increased from 24.8% to 28.7%.

Are Standard Mail volumes likely to continue to increase to allow the USPS to remain financially viable? As noted above, Standard Mail is used primarily for bulk advertising. Currently, the USPS has a considerable cost advantage in providing saturation advertising for a given geographic area through its local delivery network. This is unlikely to change in the foreseeable future, although local newspapers do provide some competition through advertising inserts. However, the declining number of subscribers to most local newspapers seems to imply continued dominance of the USPS in the delivery of saturation advertising. Significant electronic substitution, nevertheless, seems plausible in the provision of bulk advertising, as the fraction of US households with computers increases. For example, to deliver a coupon for a limited time special price, a business can use electronic alternatives that are far cheaper than printing an advertising letter and coupon and using Standard Mail to deliver it to all households in a geographic area.

Package delivery services are another growing source of revenue for the USPS. Although package delivery services revenue were 3.3% of total mail revenue in 2006, package delivery services revenue have increased at slightly less than 3% per year between 2000 and 2006. Despite these revenue increases, the USPS continues to face competition from United Parcel Service (UPS) and other package delivery companies. Consequently, it is unclear how much the USPS can increase the price for package delivery services. Therefore, it seems reasonable to conclude that package delivery services cannot be relied upon to make up for significant future USPS revenue losses.

As should be clear from the above discussion, the USPS will continue to face competition from electronic alternatives for virtually all of the services it provides. Revenue from the household sector is likely to continue to decline or remain flat, depending on the magnitude of postal rate increases. Revenue from business mailers should continue to grow. Though many of the business uses of USPS services have electronic substitutes, most of them require coordination between business mailers and their customers, which makes electronic substitution less likely to occur in the near term. Our empirical results and the above discussion of postal operations suggest that the USPS should focus future price increases in the areas not intensively used by the household sector such as Presorted First-Class Mail and Standard Mail, because price increases to increase revenue for single-piece First-Class Mail may be self-defeating given the own-price elasticity estimates we have estimated.

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Appendix. Variance covariance matrix of composite errors for model

Our econometric model in Section 3 consists of the four equations — the household decision to own a computer, the decision to purchase postage, the choice of the level of postage consumption, and the choice of the level of total non-durable good expenditures. The variance covariance matrix of composite errors to these four equations is given by

$$\begin{pmatrix} \sigma_\theta^2 + \sigma_{\epsilon_c}^2 & \rho_d\sigma_\theta^2 & \rho_w\sigma_\theta^2 & \rho_m\sigma_\theta^2 \\ \rho_d\sigma_\theta^2 & \rho_d^2\sigma_\theta^2 + \sigma_{\epsilon_d}^2 & \rho_d\rho_w\sigma_\theta^2 & \rho_d\rho_m\sigma_\theta^2 \\ \rho_w\sigma_\theta^2 & \rho_d\rho_w\sigma_\theta^2 & \rho_w^2\sigma_\theta^2 + \sigma_{\epsilon_w}^2 & \rho_w\rho_m\sigma_\theta^2 \\ \rho_m\sigma_\theta^2 & \rho_d\rho_m\sigma_\theta^2 & \rho_w\rho_m\sigma_\theta^2 & \rho_m^2\sigma_\theta^2 + \sigma_{\epsilon_m}^2 \end{pmatrix},$$

where we impose the normalizations that $\sigma_\theta^2 + \sigma_{\epsilon_c}^2 = 1$ and $\rho_d^2\sigma_\theta^2 + \sigma_{\epsilon_d}^2 = 1$. Table 7 reports the estimates of the parameters of this covariance matrix and their standard errors.

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