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ABSTRACT

A recent literature has advanced the use of Engel curves to estimate overall CPI bias. In this paper, I show that the methodology is sensitive to the modeling of household demography. Existing estimates of CPI bias do not account for the changing effect of household size on budget shares, and this can lead to omitted variable bias. Since the effect of household size on demand changes over time the drift in Engel curves attributed to CPI bias is partially explained by this effect. My estimates of the annual rate of CPI bias from 1888 to 1935 are changed by at least 25%, and usually more than 50%, once the changing effect of household size is accounted for.

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1 Introduction

Estimates of historical real income are only as accurate as the price series used to deflate them. Although there are numerous methodologies proposed to detect and correct the bias in contemporary price series, for the past we are left with few (if any) options. Even if one is uninterested in the sources of bias themselves, many would be interested in the results– the revised estimates of real income that result from corrected estimates of the Consumer Price Index (CPI). Indeed, our estimates of economic performance would change considerably if we find that our historical price series contain substantial bias. To the extent that macroeconomic models hope to fit the historical data, corrected income estimates for the past have numerous implications.

Measuring changes in the cost-of-living is a central goal of economic analysis and measurement. Without accurate measures of inflation, the inflation-targeting of monetary policy would be seriously compromised. Similarly, without estimates of real income, it is impossible to accurately measure economic growth, or to test empirical relationships between economic performance and other factors. While there are numerous problems with estimating changes in the cost-of-living, Hausman (2003) identifies four broad classes of bias in the CPI. Substitution bias occurs when consumers move to relatively less expensive goods, new goods bias arises because the CPI fails to incorporate the introduction of new items in a consumer's basket of goods, quality change bias occurs when the CPI fails to measure improvements in existing goods over time, and outlet bias occurs when consumers purchase items at low-priced stores. These sources of bias have been known for some time and there are solutions for each problem (Boskin, et al. 1996). Implementation of some corrections, however, has lagged.

In addition to the large literature that looks at CPI bias in or for specific goods, recent studies have documented the fact that the CPI contains a substantial overall upward bias. Using household level data, Costa (2001) and Hamilton (2001) use Engel curves to estimate CPI bias. Engel's Law, which says that the share of the budget devoted to food decreases with total expenditure, is one of the most persistent regularities in empirical economics. Costa and Hamilton use this regularity and argue that, conditional on household characteristics and income, differences in real income and predicted expenditures would be due to bias in the prices that are used to deflate income. Essentially, drift in Engel curves over time for similar households would be due to mismeasured real income. There are three key advantages to this approach. First, it allows us to estimate the extent of overall bias in the CPI, not only the bias of particular goods. Secondly, since the method uses survey data to estimate CPI bias, one could derive cost-of-living indices for separate groups in the population, or for groups whose cost-of-living may be unknown. For example, Costa (2001) was able to produce the first estimates of CPI bias before 1970. Third, the data requirements are relatively small, and as such CPI bias can be estimated for both present and past populations if sufficient data exist. Given these strengths, others have adopted the approach and have estimated CPI bias for other countries. Beatty and Larsen (2005) use Engel curves to estimate bias in the Canadian CPI; Gibson, Stillman, and Le (2004) for Russia; Larsen (2007) for Norway; and de Carvalho Filho and Chamon (2006, 2007) for Brazil and Mexico. Others have extended the approach– Papalia (2006) estimates regional CPIs for Italy and Almas (2007) extends the methodology across countries to estimate Purchasing Power Parity (PPP) bias.

A weakness of the approach is that it is based on a time residual– the drift in the Engel curve not explained by household characteristics or CPI-deflated income. Any omitted variable that effects demand and is correlated with time will be conflated with CPI bias. In this paper, I concentrate on a straightforward example– household size. Household characteristics are a determinant of household demand systems. There are several reasons to expect household size to exert an independent effect on demand, holding household composition fixed. Indeed, Engel's Second Law notes that households of the same proportional composition but differing sizes could be welfare equated at different expenditure levels. This effect could naturally change over time for the same reasons that the CPI may be overstated– large households may purchase more goods in bulk– lowering the price paid for them (a type of outlet bias). Larger households may exhibit different shopping patterns than smaller households. If there are scale economies in the household, large households will face lower prices for public goods than private goods, and this would lead to differing substitution bias for larger households, although the direction of that bias is not clear.[1] This is important insofar as the Engel approach to CPI bias will capture outlet bias and substitution bias, but will not capture quality change or new goods bias (Hausman 2003). As such, both of the bias types captured by the Engel method may

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[1] While the income and substitution effects for public goods go in the same direction, they move in opposite directions for private goods. See Barten (1964), Deaton and Muellbauer (1980), and Nelson (1988) for more on the theory of household economies of scale.

be influenced by the effect of household size on demand– the open question is whether the impact of household size on these biases can be considered a form of CPI bias, especially in light of the fact that the interpretation of the effect of household size on demand has proved controversial (Deaton and Paxson 1998, Gan and Vernon 2003, Logan 2007).

Costa (2001) and Hamilton (2001) do not estimate CPI bias independent of changes in the effect of household size on demand. In this paper I revisit the estimates of CPI bias from 1888 to 1935. The period from the late nineteenth century to the middle of the twentieth century is important for several reasons. First, the growing pace of industrial production in the United States during this time led it to become the world's leading economic power. As such, this is the period of American ascendancy. Second, the peak of output in the late 1920s serves as the point where we measure the trough of the Depression era– the severity of the decline in real output, consumption, and investment are all sensitive to bias in price series. Third, unlike our contemporary estimates of CPI bias, the methodology proposed by Costa and Hamilton is the only one available for the vast majority of historical periods. It is therefore very important that we establish the method's accuracy.

In this paper, I show that the effect of household size, separate from the effects of household composition, has changed dramatically over time. I then show that the Hamilton-Costa CPI bias methodology, which attributes differences in food shares over time not explained by household characteristics and relative price changes to CPI bias, implicitly assumes that the effect of household size is unchanged over time, although this is not the stated intent of their methodology. Although this problem falls under the category of omitted variable bias, it is bias of a peculiar type– the effect of household size was not omitted in the traditional sense of the phrase, but was explicitly assumed not to vary at all over this time period. Given the large changes in the effect of household size on demand, estimates of CPI bias may be overstated.

To gauge the magnitude of the bias I modify the estimation procedure, using an Engel curve that controls for both household composition and size but also allows the effect of household size to vary over time independent of CPI bias. I then estimate CPI bias with and without controls for the changing effect of household size. When I estimate CPI bias in a way that controls for changing household size effects my CPI bias estimates, while still statistically significant, are reduced by at least 25%, and usually more than 50%. When I extend the analysis to items beyond food the central implications are unchanged– allowing the effect of household size to change over time dramatically alters estimates of CPI bias. These results suggest that household size not only effects demand, but the measurement of real income as well. Much of what the methodology attributes to CPI bias is actually the changing effect of household size on demand.

2 The Changing Effect of Household Size on Demand

To consider the effects of household size on demand I estimate the demand for food with American household survey data covering 1888 to 1935. The survey data used here comes from three national consumer expenditure surveys taken in 1888-1890, 1917-1919, and 1935-1936, the same as those used in Costa (2001). The surveys are the Department of Labor's Cost of Living of Industrial Workers in the United States and Europe (1888-1890), the Bureau of Labor Statistics' Cost of Living in the United States (1917-1919), and the Department of Labor's and Department of Agriculture's Study of Consumer Purchases in the United States (1935-1936). Each survey is a large national survey of consumer expenditures and these surveys are comparable insofar as they each detail household expenditures, income, and household composition. Similarly, each survey used a similar methodology, interviewing subjects in their homes, verifying expenditures where possible, and using consistent categories for goods.[2] In addition, each survey has comprehensive demographic information on all household members, which allows us to measure the effect of household size separate from the effects of household composition. As Costa (2001) notes, since the surveys are broadly consistent with one another it is possible to derive trends in demand from them.

Since the goal here is to look at the effect of household size on demand, the Engel curve will need to distinguish between the two effects. I use the standard Rothbarth specification to separate the effect of household size from household composition on the budget share. The regression takes the form

$$w = \alpha + \beta \ln\left(\frac{x}{n}\right) + \gamma \ln n + \sum_{k=1}^{K-1} \delta_k \left(\frac{n_k}{n}\right) + \zeta z + \varepsilon \tag{1}$$

where w is the budget share, x is total expenditure, n is household size, k is a grouping of the household by age and sex (such that n_k/n is the fraction of the household belonging to demographic

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[2] See the data appendix for more information on the data sources, including survey construction and summary statistics. See Costa (1999, 2001) for more on the comparability of the 1888, 1917, and 1935 surveys. Due to the lack of comparability with later consumer expenditure surveys, this paper concentrates on the oldest suverys.

group k), and z is a vector of control variables including the fraction of the household that is employed, geographic (state) controls, and the industry that employs the head of the household.[3] The composition of the household is broken into 5-year age-sex categories up to the age of 25. The effect of household size on demand is γ.

Table 1 shows summary statistics from the three historical surveys. The average share of the budget devoted to food does decrease over time, but household size changes little in the surveys from 1888 to 1917. Table 1 also shows estimates of the effect of household size on the food share in 1888, 1917, and 1935. The coefficients in the table show the effect of household size on the budget share devoted to food (γ) for each year using an OLS regression. For example if household size were doubled in 1888, the share of the food budget share would decrease by roughly 2.3%.[4] There are several items of interest in Table 1. As the table shows, the effect of household size on demand, holding household composition constant, changes significantly over time. We can also compare these historical estimates of the scale economy to contemporary estimates. Deaton and Paxson's (1998) estimate for 1990 from the Consumer Expenditure Survey, -.008, is significantly lower than any of the historical estimates in Table 1. As such, the effect of household size on demand has changed significantly over time both in the historical data and in comparison to contemporary estimates.

3 CPI Bias and Household Size

3.1 Measuring CPI Bias with Engel Curves

There are several reasons to use consumer expenditure surveys to estimate CPI bias. As Hamilton (2001) argued, estimates of CPI bias for particular populations would tell us more about living standards than aggregate estimates of real income. Similarly, household surveys can act as a check against our estimates of real income by seeing if consumer expenditures agree with the estimates of price changes. Costa (2001) has argued that, due to data limitations, household surveys are likely the only source available to estimate CPI bias in the past. Using Engel curves to capture CPI bias hinges on the fact that Engel curves relate the budget share to real household income. If food's share of the budget moves more or less than we would predict given estimates of changes in prices (from,

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[3] As relative prices are fixed, the geographic controls would caputure the effect of differences in relative prices across space.

[4] More precisely, the effect of doubling household size would be $\gamma * \ln(2)$ (where $\ln(2) = .693$).

say, the CPI), then movements in real income, measured directly from the Engel curve, would tell us about mis-measurement of real income from sources such as the CPI. The methodology is entirely general, any expenditure category could be used. The availability of price indices for food over long time spans leads food to be the primary expenditure category used since changes in relative prices must be controlled for.

Estimating CPI bias from Engel curves requires a number of assumptions. Decomposing food and non-food expenditures into a price index and quantity index requires that food be additively separable in the household's utility function. Furthermore, there must be homotheticity in the subutilities of food and non-food. With these conditions the bias of non-food does not effect the foodshare through complementarities of substitutabilities through some unmodeled channel. Hamilton (2001) further notes that food is chosen because (1) it has an income elasticity that is sensitive to the measurement of income, (2) it is non-durable and therefore not subject to stock and flow effects (this would, naturally, be stronger in the past than today), (3) food does not involve the troublesome "definitional problems" of other expenditure categories and (4) because the Working-Leser Almost Ideal Demand System (AIDS) has a functional form that has successfully estimated the demand for food. It is also important to note that the method requires the dependent variable to be the budget share for food– food consumption and expenditure are likely to contain CPI bias themselves.

Beginning with the Almost Ideal Demand System for food

$$w_{i,j,t} = \phi + \varphi \left(\ln P_{F,j,t} - \ln P_{N,j,t}\right) + \beta \left(\ln Y_{i,j,t} - \ln P_{j,t}\right) + X\theta + u_{i,j,t} \tag{2}$$

where w is the share of the budget devoted to food, P is the true, unobserved price index for food (F), nonfood (N), and all goods, Y is household expenditure, X is a vector of household characteristics, and u is the error term; note that the true cost of living in year t, in place j, $P_{j,t}$, is a weighted average of the prices of food and non-food

$$\ln P_{j,t} = \alpha \ln P_{F,j,t} + (1 - \alpha) \ln P_{N,j,t}$$

and those prices are measured with error (which is CPI bias) such that

$$\ln\left(P_{j,t}\right) = \ln\left(P_{j,0}\right) + \ln\left(1+\Pi_{j,t}\right) + \ln\left(1+E_{j,t}\right) \tag{3}$$

where P_0 is the true price at time 0, Π is the CPI, and E is the cumulative measurement error in the price index from year 0 to year t. Note that the measurement error would also apply to the prices of food and non-food in the same manner, and that aggregate error would also be a weighted average of the errors in food and non-food. Substituting (3) into the Almost Ideal Demand System (2) and rearranging terms yields

$$\begin{gathered} w_{i,j,t} = \phi + \varphi\left[\ln\left(1+\Pi_{F,j,t}\right) - \ln\left(1+\Pi_{N,j,t}\right)\right] + \beta\left[\ln Y_{i,j,t} - \ln\left(1+\Pi_{j,t}\right)\right] + X\theta + \\ \varphi\left[\ln P_{F,j,0} - \ln P_{N,j,0}\right] - \beta\ln\left(P_{j,0}\right) + \varphi\left[\ln\left(1+E_{F,j,t}\right) - \ln\left(1+E_{N,j,t}\right)\right] - \beta\ln\left(1+E_{j,t}\right) + u_{i,j,t} \end{gathered}$$

The functional form of estimating CPI bias (the Hamilton-Costa form)

$$w_{i,j,t} = \phi + \varphi\left[\ln\left(1+\Pi_{F,j,t}\right) - \ln\left(1+\Pi_{N,j,t}\right)\right] + \beta\left[\ln Y_{i,j,t} - \ln\left(1+\Pi_{j,t}\right)\right] + X\theta + \sum_{t=1}^{T}\delta_t D_t + \sum_{j=1}\delta_j D_j + u_{i,j,t} \tag{4}$$

follows directly. Any CPI bias will be captured in δ_t, since two households with the same inflation adjusted expenditures and demographic composition should have the same shares of the budget devoted to food, since changes in relative prices are accounted for and income has been deflated. If the Engel curve is stable over time, changes in the foodshare would be due to the mis-measurement of real income over time– CPI bias. Since we now have

$$\delta_t = \varphi\left[\ln\left(1+E_{F,j,t}\right) - \ln\left(1+E_{N,j,t}\right)\right] - \beta\ln\left(1+E_{j,t}\right)$$

if we assume that the bias between food and non-food is constant and that both food and nonfood are equally biased it holds that

$$\ln\left(1+E_{j,t}\right) = \tfrac{-\delta}{\beta}$$

such that cumulative (percentage) CPI bias at t is

$$1 - \exp\left(\tfrac{-\delta}{\beta}\right)$$

It is worth noting that this methodology does not require income to be deflated. If income were not deflated in the Engel curve then δ_t would be used to estimate the true cost of living rather than bias in that cost. The method does require estimates of relative price changes over time, as these would have an effect on the demand for food.

If data on CPI measured relative price changes by region are unavailable, estimates of relative price changes over time would collapse into the time dummy as there would be no regional variation. This is the circumstance for the 1888-1917 estimates of CPI bias. In this instance, the Engel cure used to estimate CPI bias is

$$w_{i,j,t} = \phi + \beta \left[\ln Y_{i,j,t} - \ln\left(1 + \Pi_{j,t}\right)\right] + X\theta + \sum_{t=1}^{T} \delta_t D_t + \sum_{j=1} \delta_j D_j + u_{i,j,t}$$

where now

$$\delta_t = \varphi \left[\ln\left(1 + \Pi_{F,j,t}\right) - \ln\left(1 + \Pi_{N,j,t}\right)\right] + \varphi \left[\ln\left(1 + E_{F,j,t}\right) - \ln\left(1 + E_{N,j,t}\right)\right] - \beta \ln\left(1 + E_{j,t}\right)$$

so that with the same assumptions as those above, and for a given value of φ and changes in relative prices, the cumulative CPI bias at t is

$$1 - \exp\left(\frac{\delta - \varphi\left[\ln\left(1+\Pi_{F,t}\right) - \ln\left(1+\Pi_{N,t}\right)\right]}{-\beta}\right)$$

I use the estimate of φ from the 1917/1935 CPI bias regressions to estimate the 1888/1917 CPI bias, which is the same methodology adopted in Costa (2001).

The issue of changing household size effects concerns variables in the matrix X, which contains the household's composition. Since a household of size n can be disaggregated into a finite number of distinct groups, such that $n = \sum_{i=1}^{N} n_i$, both Hamilton and Costa estimate the regression in (4) with disaggregated household size

$$w_{i,j,t} = \phi + ... + \sum_{i=1}^{N} \theta_i n_i + ... + u_{i,j,t} \tag{5}$$

The functional form in (4) controls for household composition and the effects of household size simultaneously. The Hamilton-Costa form cannot separate the effects of household size and composition, it implicitly assumes that not only composition, but also household size induce the same change on the food budget share over time. While one can change composition and not household size, one cannot change household size without changing composition. It is impossible to estimate CPI bias while controlling for changes in the effect of household size on demand with the demographic modeling that Hamilton and Costa use. While one may want to assume that household composition has the same effect on demand over time, the empirical results in Table 1 give us strong evidence that the effect of household size on demand varies over time. Since the effect of household size does vary with time, the estimates of δ_t that Hamilton and Costa attribute to CPI bias may be due to household size effects' correlation with time.[5] As Hausman (2003) notes, the "key identifying assumption (besides functional form) is that the expenditure elasticities remain constant over time for a given category of expenditure after controlling for demographic characteristics" (p. 38). If the effects of demographic characteristics themselves change over time, these will be conflated with CPI bias.

3.2 Correcting the Household Size Bias

Hamilton (2001) concedes that the method, which is indirect, attributes all movement in the Engel curve unexplained by the other variables to CPI bias. If there are missing variables from the regression, or if there are errors in variables, then estimates of CPI could be spurious, overstated, or understated depending on the particular specification problem. Fortunately, incorporating changes in the effects of household size on demand is straightforward. Since the regression is an Engel curve (and differs from the Hamilton Costa form only in being in per capita terms) the methodology employed earlier can be used to estimate CPI bias while at the same time controlling for changing household size effects.[6] Recall that the earlier regression took the form

$$w_f = \alpha + \beta \ln\left(\tfrac{x}{n}\right) + \gamma \ln n + \sum_{k=1}^{K-1} \delta_k \left(\tfrac{n_k}{n}\right) + \zeta z + \varepsilon$$

which disaggregates the effects of household composition and changes in household size on demand by design. This functional form can be easily augmented to estimate CPI bias by including terms for changes in relative prices, deflating per capita income, and including variables for time and region.[7] The regression now becomes

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[5] Hamilton (2001) describes robustness checks to his specification, which included adding covariates, interacting income with other covariates, and an instrumental variables specification. None of these robustness checks interacted household demography measures with time.

[6] None of the assumptions needed to estimate CPI bias with Engel curves is violated by using the functional form outlined here.

[7] Note that regional (state) effects were controlled for in the estimates of scale economies discussed in the previous section.

$$w_{i,j,t} = \alpha + \varphi\left[\ln\left(1+\Pi_{F,j,t}\right) - \ln\left(1+\Pi_{N,j,t}\right)\right] + \beta[\ln\left(\tfrac{x}{n}\right)_{i,j,t} - \ln\left(1+\Pi_{j,t}\right)] + \gamma \ln n + \sum_{k=1}^{K-1} \delta_k \left(\tfrac{n_k}{n}\right) + \lambda\left[(\ln n) * D_t\right] + \sum \delta_t D_t + \sum \delta_j D_j + u_{i,j,t} \qquad (6)$$

so that changes in the Engel curve that derive from changing household size effects can be estimated separate from estimates of CPI bias. If changing household size effects have an effect over time on movements in the Engel curve (if λ is statistically different from zero) then the specification in (6) will capture it, and estimates of δ_t will not suffer from the omission of changing size effects. This reformulation not only corrects for omitted variable bias due to changing household size effects, but also formally test the proposition that household size effects have changed over time, independent of changes in real income.

There are two important caveats to this approach. First, the magnitude of the omitted variable bias is a function of the type of data that one wishes to use to estimate CPI bias. For example, the correction noted above is unlikely to result in significant revisions for annual panel data based estimates of CPI bias. Indeed, part of the reason that this issue may have been overlooked is due to the fact that Hamilton used the Panel Study of Income Dynamics (PSID) to estimate CPI bias in the 1970s, and this gave him annual observations of the same families over time. One of the arguments for use of the methodology, however, is that it allows us to estimate the cost of living for specific groups in the population, and we are unlikely to have annual panel data for every population whose living standards we are interested in. In fact, it is most likely that we would be interested in populations (both historical and contemporary) that we have relatively few repeated samples from, and as such this correction may be needed *most* for populations whose cost of living would be best estimated by this approach because they would be difficult to estimate from other sources.

Secondly, it is useful to distinguish the issue here, about estimates of CPI bias that may suffer from omitted variable bias, from the general issue of modeling demographic variables in demand analysis. I am concerned with the fact that household size may have a time varying effect on changes in demand, and should therefore be included in estimates of CPI bias that seek to control for changes in household composition. A separate issue is the modeling of demographic variables in demand equations in a way that is theoretically consistent. See Pollack and Wales (1979, 1980, 1981) and Lewbel (1985) for classic references on this issue, and Blundell, et. al. (2003) for the non-parametric case. While I make no claims about the proper modeling of demographic variables in demand systems, it is important to note that the discussion above is an example of the modeling of demographic variables in demand systems. If Engel based estimates of CPI bias are sensitive to the effects of household size on demand, estimates of CPI bias should purge the effects of household size from estimates of CPI bias.

Naturally, there are concerns about the method given above as well. For example, one has to argue that preferences stay fixed over this (admittedly long) time period, and the welfare interpretation of family size is unclear in the literature. Similarly, there are limits to the data at hand, which is not a probability sample of the US population but targeted household surveys. But a defense of such critiques can be made. First, concerns about stable preferences and data limitations would also apply to Costa's original estimates. Secondly, what I term here as omitted variable bias is a peculiar type– the variable was not omitted in the traditional sense of the phrase, but it was explicitly assumed not to vary at all over this time period. Indeed, it is Costa and Hamilton's methodology that assumes that household size's effect remains unchanged over time, which seems to be the more restrictive assumption. Third, although Costa and Hamilton concede that anything correlated with time will influence the results, what I note above is that a variable available to them in their original formulation has the potential to revise the estimates of CPI bias substantially. As such, this is not a correction involving an additional variable, but a problem in their econometric specification. As noted earlier, such a correction is important if one would wish to use this method to correct for CPI bias in the past.

4 CPI Bias and Household Size

4.1 Revised Engel Estimates of CPI Bias

Table 2 shows estimates of CPI bias with and without controlling for changing household scale economies. As further confirmation of the changing economies of scale over time, the year and household size interaction terms are statistically significant in both sets of regressions. As predicted, estimates of CPI bias decrease once the changes in household size are included, and the differences in the estimates of CPI bias are striking, reduced by 25% or more.[8] For 1888 to 1917, controlling for changes in household size reduces the estimate of CPI bias by nearly three-fold. For 1917 to 1935, controlling for changes in scale economies reduces the estimate of CPI bias by 25%. As expected,

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[8] These estimates of CPI bias should not be considered revisions of Costa's (2001) estimates. Our baseline CPI bias estimates will differ both because of methodology and the CPI series being corrected differ (Costa uses estimates of CPI from the 1975 edition of the *Historical Statistics of the United States* while my estimates come from the 2006 edition). The focus here is on the difference between the household size corrected and uncorrected estimates.

the inclusion of the interaction decomposes the Hamilton-Costa "CPI bias" into the changing effect of household size and a time residual. For example, if one adds the coefficient on the "Year is 1917" variable to the household size-year interaction evaluated at the mean in Column II of Table 2, the result is equal to the "Year is 1917" coefficient in Column I.[9] Unless one wished to argue that the changing effect of household size on demand is a form CPI bias, the lessened size of the time residual substantially reduces the CPI bias estimates.

The stated goal of the Hamilton-Costa specification is to assume that composition effects are time invariant. As Costa (2001) explains "If the O'Grady's in 1919 had the same total CPI-deflated household expenditures as the Svensons in 1935 and both families had the same number of children, then I attribute differences in their food and recreation shares to CPI bias, controlling for changes in relative prices" (p. 1292). To the extent that compositional effects do change over time, however, the Hamilton-Costa framework may attribute changes in compositional effects of demand to CPI bias. In Table 8 I fully interact household composition and size with time, and this results in further refinement of the CPI bias estimates. When household composition is allowed to have time varying effects, the estimated CPI bias changes dramatically. For 1888-1917, the fully interacted model resulted in a "Year is 1917" coefficient estimate of 0.015, which was not statistically significant. For 1917-1935, the "Year is 1935" coefficient changes sign (0.029), but is statistically significant. In short, fully interacting the model with compositional change causes the CPI bias to disappear from 1888 to 1917, and a change in the direction of the bias from 1917 to 1935.

Figure 1 shows these differences in CPI estimates from the historical CPI. In the figure the differences between the new and historical CPI estimates are plotted against time. As the figure shows, both the household size and fully interacted estimates revise downward CPI bias estimates from 1888 to 1917, but from 1917 to 1935 the CPI bias estimates vary widely based on the modeling of household size and composition changes. Figure 2 shows estimates of the CPI itself from 1888-1937 with and without household size bias corrections. These new estimates of CPI bias revise estimates of consumer expenditures/consumption as well. Figure 3 shows CPI deflated real expenditures from 1900 to 1937. As the figure shows, the household size corrected estimates of real expenditures are closer to the CPI deflated real expenditure estimates than the uncorrected estimates, and the Hamilton/Costa estimates are the lowest estimates of real expenditure from 1888 to 1917 and the largest for 1917 to

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[9] In general, it should hold that $\delta_{t,uncorrected} = \delta_{t,corrected} + \lambda\left(D_t * \ln\left(\overline{n}\right)\right)$. In the case of Columns I and II of Table 2, this is .026 + (.025)*(ln 5)=.066, which is close to the coefficient from Column I of Table 2 (.065).

1935. Controlling for changes in household size over time has a significant effect on estimates of CPI bias and real expenditure in the past.

Table 2 also shows two interesting facts. First, the inclusion of household size change over time does not impact the effect of income on demand, so household changes do not appear to have an effect that works directly through income itself. Secondly, changes in household size do not fully explain CPI bias. Even after controlling for changing household size and composition with time, there is still drift in the CPI that can be attributed to CPI bias, and it is significant in the 1917/1935 regression. The inclusion of other time varying variables (such as changing household compositional effects) further revises the CPI bias estimates, however, suggesting that the Hamilton-Costa form is sensitive to changes in household size and composition.

4.2 Further Estimates of CPI Bias

As mentioned earlier, CPI bias can be estimated for other consumption categories besides food, given that they satisfy the conditions noted above. To see how the CPI estimates vary for different consumption categories I estimated CPI bias based on expenditures for entertainment and clothing. An important caveat with these results (that does not apply to the food estimates) is that price indices for clothing and entertainment may over- or under-estimate the regional differences in prices more so than the food estimates, since the food estimates were derived from city-level estimates. Given that we do not have estimates of entertainment and clothing price indices for this period I interpolated the regional price indices for these items using the food and overall price indices by region for 1917 to 1935. This may cause problems for the estimates of baseline CPI bias, especially since the 1888/1917 estimates require the estimate of φ from the 1917/1935 regressions. Even with this caveat, the sensitivity of the results to the modeling of household size and composition should be unaffected, unless household size is somehow correlated with the price index in the *Historical Statistics of the United States*, which seems unlikely.

Table 3 shows estimates of CPI bias based on entertainment expenditures. From 1888 to 1917, the correction for household size and the interaction of household composition with time actually increase the estimates of CPI bias. From 1917 to 1935, the correction and interactions have little effect on the estimates of CPI bias. Table 4 shows estimates based on clothing expenditures. For 1888 to 1917, the household size correction and composition interaction change the sign of the CPI bias, and the magnitude of the differences is large as well, larger than the differences for food from 1888 to 1917. For 1917 to 1935 the correction and composition interactions decrease the size of the bias, although all of the estimates are in the same direction. These estimates are strong confirmatory evidence that the Hamilton-Costa methodology is sensitive to the modeling of household size and composition, regardless of consumption category considered.

5 Conclusion

Estimating bias in the overall CPI is important, and the Engel approach has been advanced as a method that could correct our CPI estimates. I explored here how Engel curve estimates of CPI bias may be biased themselves if changes in household size's effect on demand are not accounted for. The results here suggest that estimates of CPI bias are changed by at least 25%, and usually more than 50%, once changes in size effects are controlled for. Even with this correction, there is still much to commend the Engel based approach. As the results here showed, the household size correction does not eliminate the CPI bias. The open question is whether the household size correction modifies our estimates of CPI bias or decomposes it. For example, if it is true that larger households are more prone to outlet bias than smaller households, then part of the household size correction should be attributed to outlet bias, and added into the overall CPI bias estimates. Is this effect CPI bias, household size bias, or a combination of the two? Since more than one type of CPI bias may be present the household effect itself, or at least the portion due to CPI bias, could be decomposed further. To do so one would need to assert that households of different types face different price changes over time, and that remains a controversial issue in CPI theory and empirics. If one holds that all households face the same prices then the results alter our Engel based estimates of CPI bias.

The results here with respect to household size are consistent with calls for group-specific CPIs. Although Boskin, et al. (1996) rejects the idea that prices may change more rapidly for some groups as opposed to others, Pollak (1995, 1998) has held that these sorts of differences are important, and that group level CPIs should be investigated further. Since households of different sizes may be more or less prone to different types of CPI bias, it may be useful to know how this decomposition of Hamilton-Costa CPI bias should influence our notion of overall CPI corrections. More research is needed on whether this household size effect may be attributed to consumption patterns that constitute CPI bias or is a time varying effect that was erroneously attributed to CPI bias.

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6 Data Appendix

6.1 The Consumer Expenditure Surveys

I used three consumer expenditure surveys in this paper, covering the years 1888-1890, 1917-1919, and 1935-1936. While theses surveys are not nationally representative, they are broadly comparable and have been used extensively to estimate historical demand systems. For the 1888-1890 survey, the sample was selected only from the following nine industries: pig iron, bar iron, steel, bituminous coal, coke, iron ore, cotton textile, wool textile and glass. Sample families, limited to those representing more than two persons, were chosen from employer records. These households were then selected to provide detailed expenditure information to survey respondents, and in most instances expenditures were verified by local merchants. Twenty-four states were covered. In total, nearly 7,000 American families were surveyed. For more on the sampling see Logan (2006).

The 1917-1919 data were obtained from the surveys over 12,000 families of wage earners or "small salaried workers." As with the 1888-1890 survey, households were selected from employer records. Sample families were chosen such that there are only husband and wife families with at least one child; the salary earners had to earn less than $2,000 per year; families had to reside in the community at least one year prior to the interview; families could not have more than three boarders; families could not be “slum” or "charity"; and non-English-speaking families had to reside in the United States for more than five years. All the selections are from ninety-nine cities throughout 42 states.

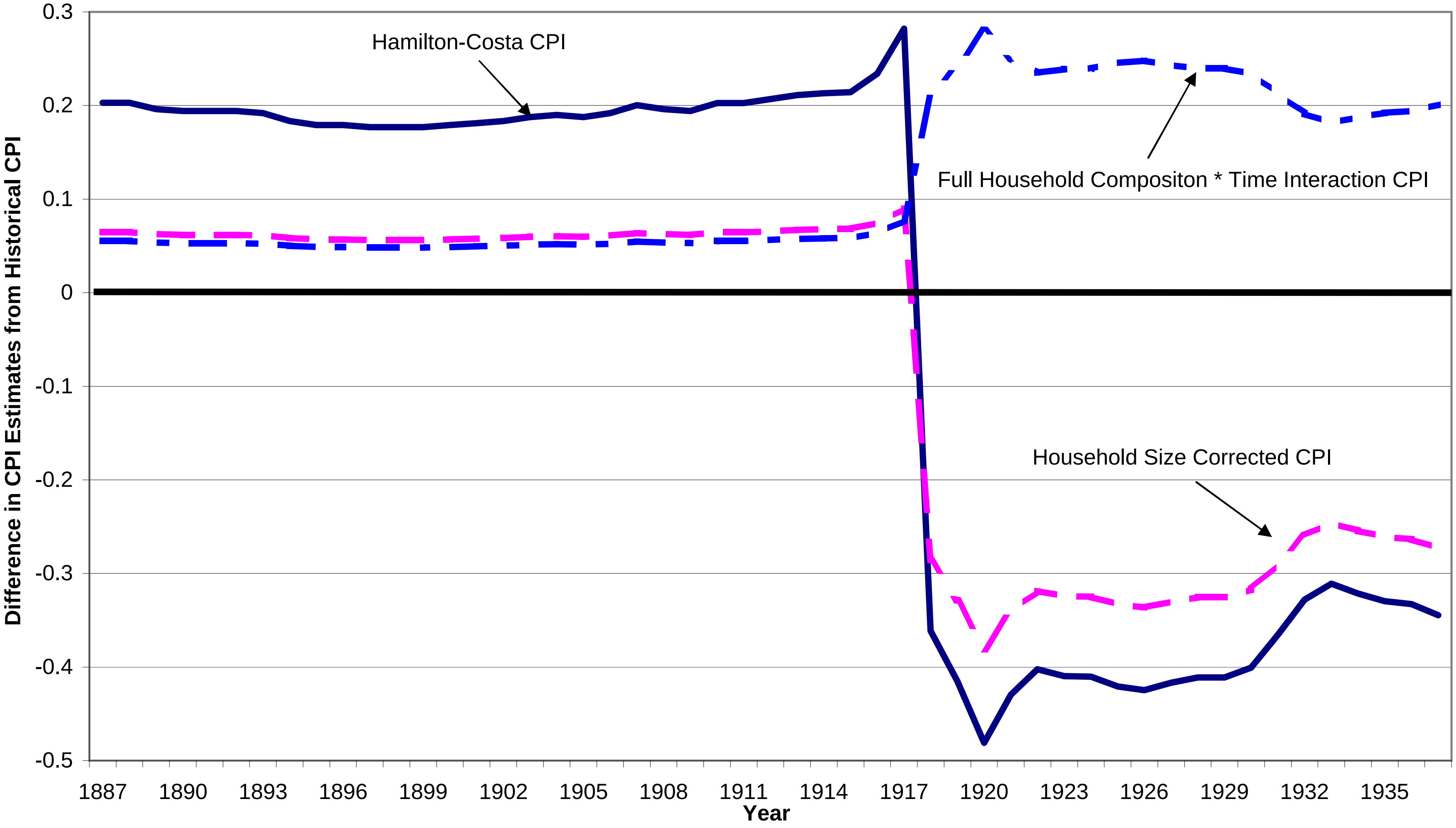
In the 1935-1936 survey, only native-born families living in the United States were selected. The sample covered 51 cities, 140 villages, and 66 farm counties throughout 30 states. Except for New York City; Columbus, OH; and the South, only white families were chosen. Families in large cities had to earn more than $500 a year and those in smaller localities had to earn more than $250 a year. There was no income limit on households in this survey, and self-employed households were included as well. The data used in this paper comes from a random sample of 6,000 families of the 61,000 who provided both income and expenditure information. Since the 1935-1936 survey was explicit in its desire to capture the expenditure of rural households, while the 1917-1919 and 1888-1890 selected almost exclusively on urban households, I used only the urban households from the 1935-1936 survey in the analysis, which is more than half of the 6,000 observations. For the estimates of CPI bias, I used the rural data as well, although due to missing values this added only 116 households from rural areas from the 1935-1936 survey and does not effect the CPI bias results.

Construction of household size in each survey was complicated by the fact that households include a non-negligible number of boarders. All of the results presented in the paper include boarders as household members. This could potentially bias the results, but in estimating the effect of household size on demand with and without boarders the qualitative results were the same, and the estimates of CPI bias (baseline compared to household change corrected) are similar. Construction of household expenditure for the three surveys was similar. While the construction of the clothing and food categories was straightforward, entertainment varies somewhat by survey. Entertainment in 1888-1890 is comprised of expenditures on books, newspapers, vacations, and "other amusements." For 1917-1919 entertainment includes expenditures on movies, concerts, plays, lectures, dances, billiards, excursions, books, and "other amusements." For 1935-1936 entertainment includes movies, radios, sports clubs, social clubs, camping, fishing, hiking, sports (golf, baseball, horseback riding, tennis, etc.), bikes, skates, skis, billiards, boats, cameras, vacations, and "other recreational expenses." For more on the difficulties of constructing time-invariant measures of entertainment, see Costa (1999).

6.2 Price Indices

Overall price change for 1888-1917 and overall and food price changes for 1917-1935 were calculated from the *Historical Statistics of the United States, Millennial Edition* (2006). For 1917-35, regional price indices were calculated using the *Handbook of Labor Statistics: 1950 Edition* (U.S. Bureau of the Census 1951) which contains price indices for 1917-1935 for food and all items for a sampling of cities in the United States. These were applied to the states from which the prices came, to construct a regional price index using the Census Bureau's regions (this gives four regions for the US). Assuming that the price index is a weighted average of food and non-food, the price indices are used to create regional price indexes for food, non-food and all items for 1917-1935.

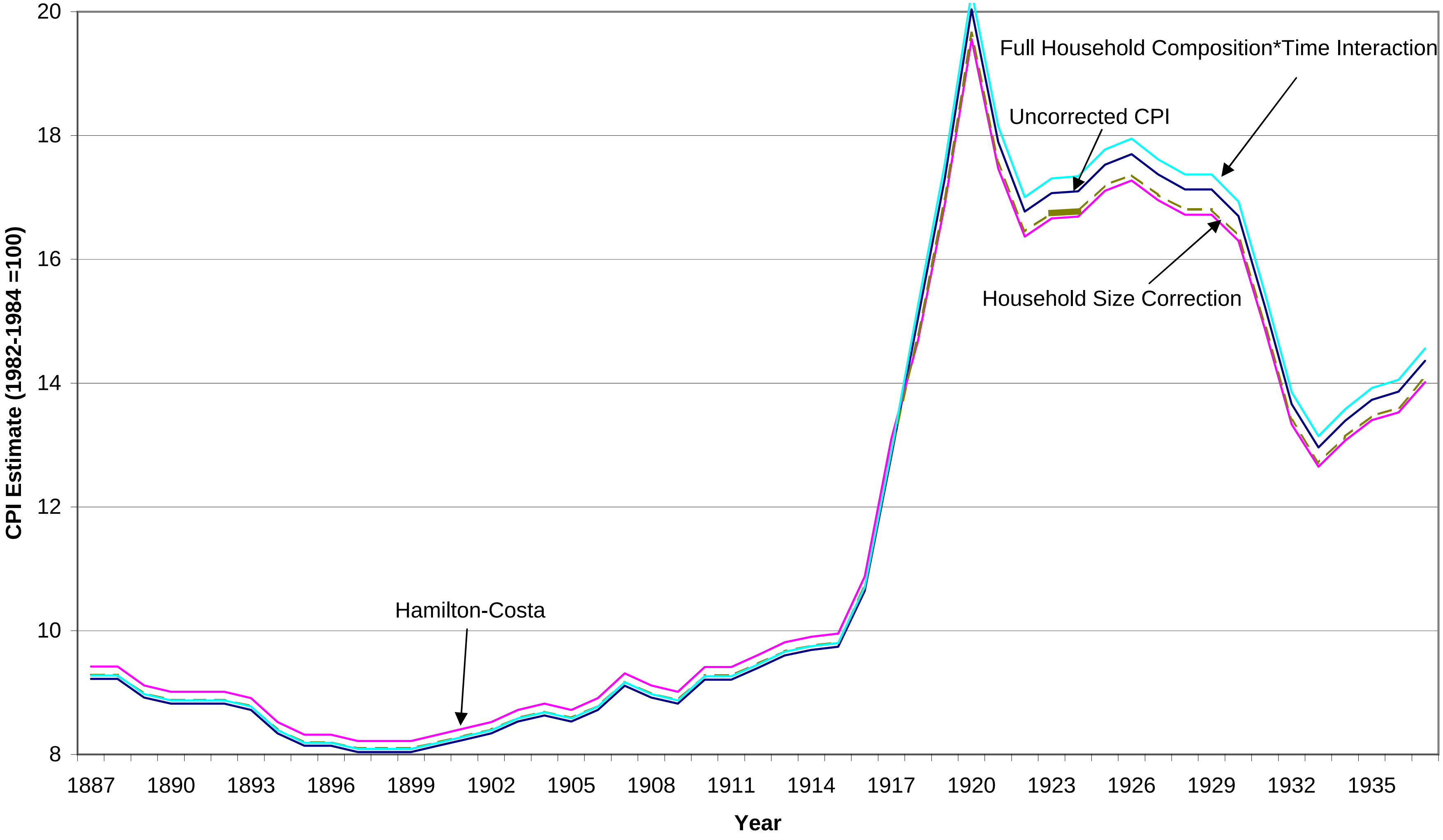
Figure 1
Difference Between Hamilton-Costa, Household Size Corrected, and Historical CPI 1887-1937



*Deviations are from CPI estimates (corrected minus uncorrected) by Lawrence H. Officer (2006), "The Annual Consumer Price Index for the United States, 1774-2005"

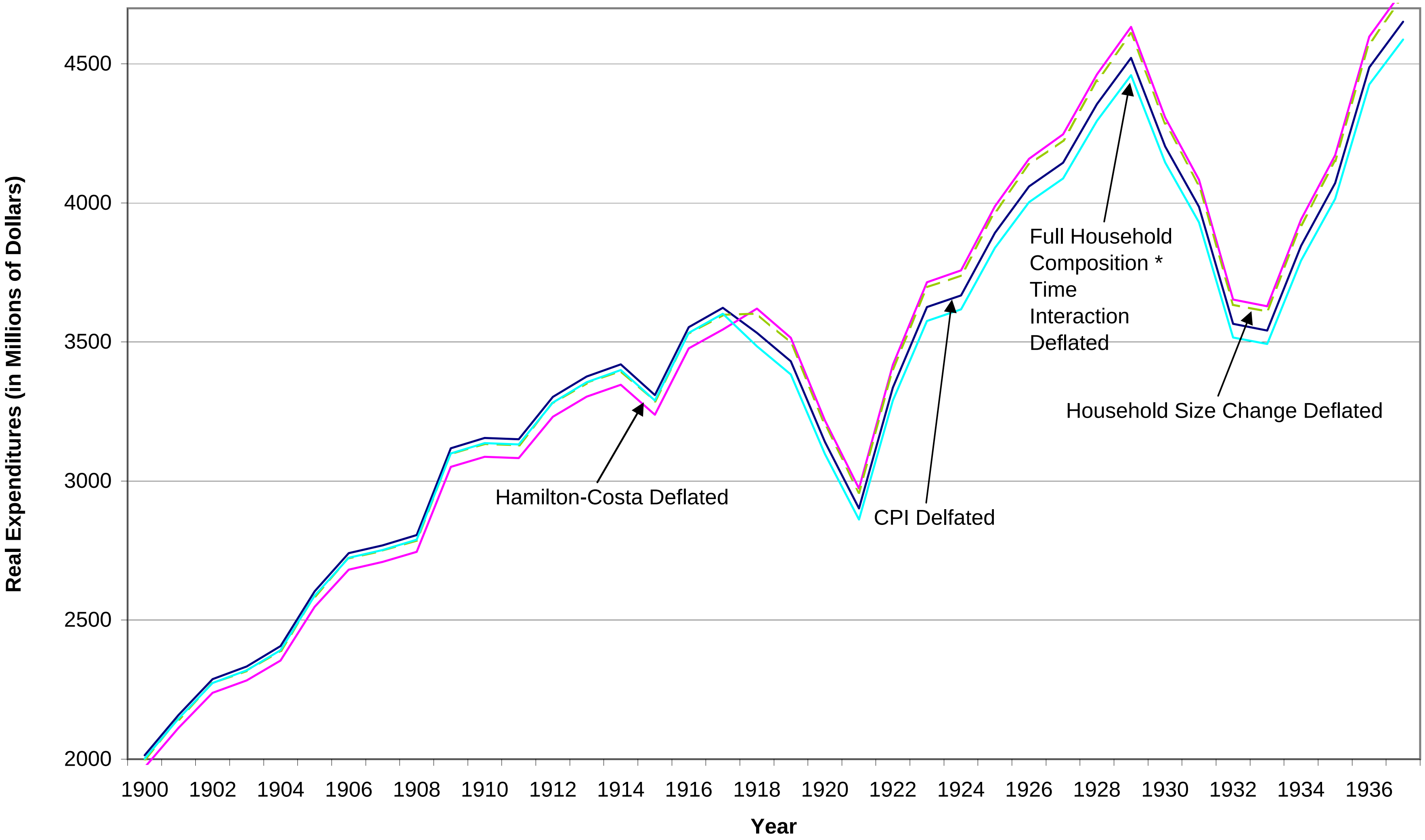
Figure 2

Corrected CPI Estimates With and Without Controls for Changing Household Size 1887-1937



*Uncorrected CPI estimates come from Lawrence H. Officer (2006), "The Annual Consumer Price Index for the United States, 1774-2005"

Figure 3
CPI Deflated Real Expenditures, 1900-1937



*Real expenditure estimates come from Susan B. Carter, et al. (2006) *Historical Statistics of the United States: Millennial Edition* .

Table 1

Summary Statistics from Historical Household Surveys, 1888-1935

	I	II	III
Variable	1888	1917	1935
Household Size	4.7 (2.11)	4.9 (1.64)	3.7 (1.45)
Food Share	44.5% (.089)	39.2% (.079)	38.9% (.093)
Clothing Share	16.7% (.065)	16.2% (.050)	10.9% (.056)
Entertainment Share	1.9% (.024)	3.2% (.009)	3.5% (.027)
Housing Share	13.7% (.081)	13.6% (.069)	14.3% (.088)
N	6809	12817	3534

Note: Estimates are the mean values, based on Author's calculation.
Standard Deviations are listed in parentheses.

The Effect of Household Size on Food's Share of the Budget 1888-1935

	I	II	III
Variable	1888	1917	1935
Log of Household Size	-0.023 (5.6)	-0.091 (32.39)	-0.040 (3.36)
N	6809	12817	3534

Note:
Each entry is the coefficient estimate for the log of household size from an OLS regression.
The dependent variable in each regression is the share of household expenditure devoted to food.
Each entry comes from a separate regression that includes the log of per capita expenditure,
the fraction of the household employed, the state of residence, the industry of the household head,
and demographic shares of the household in five year age-sex categories.

Robust t-statistics are listed under coefficient estimates in parentheses.

Table 2

Estimating CPI Bias with and without Controls for Changing Household Size, 1888-1935 (Food)

	I	II	III	IV	V	VI
	1888/1917	1888/1917	1888/1917	1917/1935	1917/1935	1917/1935
Log Real Per Capita Expenditure	-0.132	-0.131	-0.133	-0.159	-0.159	-0.156
	(73.96)	(73.11)	(75.29)	(93.82)	(93.89)	(93.89)
Log Household Size	-0.055	-0.069	-0.019	-0.101	-0.099	-0.085
	(23.44)	(24.82)	(5.34)	(35.20)	(33.62)	(27.02)
Year is 1917	0.065	0.026	0.003			
	(34.83)	(5.70)	(0.35)			
Year is 1917 * Log Household Size		0.025	-0.047			
		(9.36)	(10.64)			
Year is 1935				-0.091	-0.069	0.036
				(4.42)	(3.17)	(1.64)
Year is 1935 * Log Household Size					-0.016	0.036
					(3.15)	(4.28)
Full Demographic * Time Interaction			X			X
R-Squared	0.393	0.396	0.413	0.477	0.479	0.510
N	19626	19626	19626	16467	16467	16467
Cumulative CPI Bias	-0.633	-0.219	-0.165	0.435	0.351	-0.260
Annual CPI Bias	-0.022	-0.007	-0.006	0.024	0.019	-0.014
Annual Bias (without controls)/ Annual Bias (with controls) [Expressed as percent]		288%	366%		124%	-168%

Note:
The dependent variable in all regressions is the share of household expenditure devoted to food.
Robust t-statistics are listed under coefficient estimates in parentheses. The regressions above include relative price changes between food and non-food (by region), deflated household expenditure (by region), regional dummies, household demographics, and the fraction of the household employed.
Regressions are weighted by population size of the US to control for sample size differences (as in Costa (2001)).
Full demographic * time interaction are regressions where each household share is interacted with the "Year is 19XX" time variable.

See section 3 of the text for details on the functional form in the CPI bias regression.
See section 3 of the text for the derivation of the cumulative and annual CPI bias estimates.

Table 3
Estimating CPI Bias with and without Controls for Changing Household Size, 1888-1935 (Entertainment)

	I 1888/1917	II 1888/1917	III 1888/1917	IV 1917/1935	V 1917/1935	VI 1917/1935
Log Real Per Capita Expenditure	0.016	0.016	0.016	0.011	0.011	0.010
	(39.12)	(40.16)	(40.52)	(33.77)	(33.90)	(33.15)
Log Household Size	0.006	0.002	0.00182	0.006	0.00583	0.006
	(11.37)	(2.84)	(2.22)	(11.90)	(10.79)	(10.92)
Year is 1917	-0.024	-0.036	-0.047			
	(57.28)	(34.84)	(20.85)			
Year is 1917 * Log Household Size		0.008	0.009			
		(12.45)	(8.82)			
Year is 1935				0.064	0.059	0.061
				(16.91)	(14.82)	(14.91)
Year is 1935 * Log Household Size					0.003	-0.004
					(3.66)	(2.56)
Full Demographic * Time Interaction			X			X
R-Squared	0.203	0.209	0.220	0.327	0.327	0.333
N	19626	19626	19626	16467	16467	16467
Cumulative CPI Bias	-8.370	-18.836	-38.449	0.997	0.995	0.997
Annual CPI Bias	0.289	0.650	1.325	0.055	0.055	0.055
Annual Bias (without controls)/ Annual Bias (with controls) [Expressed as percent]		44%	22%		100%	100%

Note:
The dependent variable in all regressions is the share of household expenditure devoted to entertainment.
Robust t-statistics are listed under coefficient estimates in parentheses. The regressions above include relative price changes between food and non-food (by region), deflated household expenditure (by region), regional dummies, household demographics, and the fraction of the household employed.
Regressions are weighted by population size of the US to control for sample size differences (as in Costa (2001)).
Full demographic * time interaction are regressions where each household share is interacted with the "Year is 19XX" time variable.

See section 3 of the text for details on the functional form in the CPI bias regression.
See section 3 of the text for the derivation of the cumulative and annual CPI bias estimates.

Table 4
Estimating CPI Bias with and without Controls for Changing Household Size, 1888-1935 (Clothing)

	I 1888/1917	II 1888/1917	III 1888/1917	IV 1917/1935	V 1917/1935	VI 1917/1935
Log Real Per Capita Expenditure	0.018	0.016	0.016	0.018	0.018	0.018
	(12.71)	(11.58)	(11.41)	(16.97)	(17.11)	(17.02)
Log Household Size	0.039	0.056	0.064	0.028	0.027	0.025
	(21.53)	(25.86)	(22.39)	(15.53)	(14.30)	(12.22)
Year is 1917	-0.015	0.030	0.018			
	(10.47)	(8.63)	(2.37)			
Year is 1917 * Log Household Size		-0.029	-0.040			
		(14.16)	(11.44)			
Year is 1935				-0.026	-0.043	-0.037
				(1.97)	(3.10)	(2.59)
Year is 1935 * Log Household Size					0.012	0.013
					(3.81)	(2.43)
Full Demographic * Time Interaction			X			X
R-Squared	0.132	0.141	0.144	0.267	0.268	0.271
N	19626	19626	19626	16467	16467	16467
Cumulative CPI Bias	-2.301	0.729	0.472	-3.239	-9.901	-6.635
Annual CPI Bias	-0.079	0.025	0.016	-0.180	-0.550	-0.369
Annual Bias (without controls)/ Annual Bias (with controls) [Expressed as percent]		-316%	-487%		32.7%	48.8%

Note:
The dependent variable in all regressions is the share of household expenditure devoted to clothing.
Robust t-statistics are listed under coefficient estimates in parentheses. The regressions above include relative price changes between food and non-food (by region), deflated household expenditure (by region), regional dummies, household demographics, and the fraction of the household employed.
Regressions are weighted by population size of the US to control for sample size differences (as in Costa (2001)).
Full demographic * time interaction are regressions where each household share is interacted with the "Year is 19XX" time variable.

See section 3 of the text for details on the functional form in the CPI bias regression.
See section 3 of the text for the derivation of the cumulative and annual CPI bias estimates.