The relative importance of taste shocks and price movements in the variation of cost-of-living: evidence from scanner data

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Abstract

Intertemporal consumer preference shifts, although common in modern macro-economic models as drivers of demand shocks, have important but largely unexplored implications for price index theory and thus, for empirically measured price changes. The current practice of inflation measurement basically ignores taste changes and this study aims to fill this gap. We derive a cost-of-living index in the presence of intertemporal preference shifts and show that such taste changes tend to lower the cost-of-living. Using a large barcode level dataset that covers 331 product groups and ten countries, we then uncover the importance of taste changes in explaining consumer demand shifts across close substitutes. We also analyze how measured consumer price inflation alters after allowing for taste adjustment over time and under CES preferences. To do so, we estimate the elasticity of substitution between varieties of the same good and use those to calculate goods price indexes. Our results show that the median elasticity of substitution is around 4 and find that measured average annual goods price inflation is on average about 1.1 percent lower when taking into account consumer taste shifts compared to standard goods price indexes. Our results indicate that taste changes are an important hitherto ignored factor in the measurement of cost-of-living changes.

Key words: inflation measurement bias, cost-of-living, price index, elasticity of substitution

1 Introduction

The standard theory of the cost-of-living index assumes that preferences don't change between periods. This assumption implies that consumption patterns will alter only due to a shift in income or movement

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in relative prices. We analyze what happens if taste changes are introduced.

In this paper, we first discuss theoretically such a cost-of-living index that takes into account taste changes, following the literature by Fisher et al. (1972), Paul A. Samuelson et al. (1974), Basmann et al. (1984), Balk (1989) and Redding et al. (2016). Our definition of cost-of-living index in the presence of taste changes follows Basmann et al. (1984) and Balk (1989). To derive an analytic form for the cost-of-living index we introduce taste changes in a nested Cobb-Douglas- CES utility framework, where utility is derived by consuming from a Cobb-Douglas aggregate of different product groups which are themselves CES aggregates of individual products. We allow for different elasticity of substitution within product groups and derive the theoretical cost-of-living index. Here we are related to Redding et al. (2016) who derive a theoretical cost-of-living index, which they call unified price index, for a nested CES utility framework, where product groups and upper level aggregates both are CES. However we differ with respect to Redding et al. (2016) in our cost-of-living concept. In their analysis, changes in the cost-of-living solely depend on price and expenditure changes and not directly on changes in preferences. Contrary to this, the cost-of-living index we propose, based on Basmann et al. (1984) and Balk (1989), directly depends on preference changes.

Using a rich barcode level data set from which we can observe actual price and expenditure data for ten euro area countries and 331 product groups, finally, we estimate our derived theoretical cost-of-living index and compare it with price indexes applied in practice. To do so, we follow the methodology in Broda et al. (2010) and Feenstra (1994) to estimate the elasticities of substitution within product groups and use these elasticities to calculate the theoretical cost-of-living index. The results show that taste changes are an important element in our understanding of the evolution of cost-of-living over time. The calculated theoretical price index that takes into account taste changes turns out to be on average 1.1 percent lower than an index that ignores potential variability in consumer preferences over time.

The rest of the paper is structured as follows. Section 2 develops the theoretical framework, section 3 describes our large barcode level dataset, section 4 explains empirical analysis, section 5 presents the results and section 6 concludes.

2 Theoretical framework

2.1 Taste shocks and a cost-of-living index

This section combines the insights of Fisher et al. (1972), Paul A. Samuelson et al. (1974), Basmann et al. (1984), Balk (1989) and Redding et al. (2016), who all discuss taste changes in a utility framework. We start be recapping the traditional cost-of-living index concept. We do so as it sets the notation used later in the paper. Thereafter we introduce the concept of taste change and discuss what it implies for a cost-of-living concept.

Let $U(\mathbf{q})$ represent the utility of the consumer obtained by consumption bundle $\mathbf{q}$ and let $\mathbf{p}$ be the price vector. The expenditure function is then given by

$$e(\mathbf{U}_0, \mathbf{p}) = \min_{\mathbf{q}}\{\mathbf{p}.\mathbf{q} : U(\mathbf{q}) = \mathbf{U}_0\} \tag{1}$$

Instead of using the expenditure function, it is useful to use the money metric function C which is defined over consumption bundles and prices rather than utility levels and prices[1]:

$$C(\mathbf{q}_0, \mathbf{p}) = \min_{\mathbf{q}}\{\mathbf{p}.\mathbf{q} : U(\mathbf{q}) = U(\mathbf{q}_0)\} \tag{2}$$

where we have the relation between expenditure function and money metric: $e(U(\mathbf{q_0}), \mathbf{p}) = C(\mathbf{q}_0, \mathbf{p})$

A cost-of-living index measures the change in income (or expenditures) needed to sustain a given level of utility when prices change. The Konüs cost-of-living index at price vectors $\mathbf{p_2}$ and $\mathbf{p_1}$ and consumption bundle $\mathbf{q_0}$ is defined as the ratio of two particular values of the expenditure function or money metric function:

$$P_K(\mathbf{q_0}, \mathbf{p_2}, \mathbf{p_1}) = e(\mathbf{U}(\mathbf{q_0}), \mathbf{p_2})/e((\mathbf{U}(\mathbf{q_0}), \mathbf{p_1}) = C(\mathbf{q_0}, \mathbf{p_2})/C(\mathbf{q_0}, \mathbf{p_1}) \tag{3}$$

As discussed in more detail in Diewert (2009), this defines a family of cost-of-living indexes, one per reference quantity vector $\mathbf{q}_0$ (except in the case of homothetic preferences where the cost of living index is independent of the bundle $\mathbf{q}_0$).

In the standard literature the utility function is fixed. The cost-of-living index has a well defined meaning when holding the utility function of the consumer fixed. The consumer is indifferent between having available a budget to spend $P_K(\mathbf{q}_0, \mathbf{p_2}, \mathbf{p_1})C(\mathbf{q}_0, \mathbf{p_1})$ under the price vector $\mathbf{p_2}$ or having a budget to spend $C(\mathbf{q}_0, \mathbf{p_1})$ under the price vector $\mathbf{p_1}$. So the cost-of-living index gives the magnitude by wich the budget needs to change to keep the consumer being indifferent between two price vectors. Note that in this definition time doesn't matter. The cost-of-living index compares two constraints sets, i.e price vectors and budgets under which the consumer is indifferent. The fact that the cost-of-living concept is, in practice, mostly relevant for comparison across time, doesn't change that basic fact. If one assumes, a priori, that the same level of utility can be compared over time, i.e. utility surfaces don't change over time, and also the labelling of the utility indifference curves doesn't change, cost-of-living becomes a meaningfull concept also over time.[2]

[1] This function goes back to McKenzie (1957) who defined $M_x(p)$ being the minimum income to attain a basket at least as good as x at price vector p. Paul A Samuelson, 1974 called this function, for a fixed price vector a money-metric utility)

[2] Fisher et al. (1972) argue that even if indifference curves remain unchanged we can never be certain that over time they are not relabelled, so that intertemporal comparison, in their view of the world, is in principle never possible. They argue: "While it is apparently natural to say that a man whose tastes have remained constant is just as well off today as he was yesterday if he is on the same indifference curve in both periods, the appeal of that proposition is no more than apparent.

However, preferences can change. There is no good theoretical reason why consumers should have constant preferences over time. Even simple introspection shows that what one likes today might be quite different from what one fancied yesterday. Such a change seems to imply a change in the utility surface. To allow for such changes to take place it seems that one does not simply want a relabelling of the indifference curves but to allow for a change of curvature in the indifference curves (i.e. a change in the substitutability between items). Such changes in curvature can be obtained in a simple way by augmenting the arguments of the utility function with taste parameters. Fisher et al. (1972) define a "good-augmenting" taste change in good i as the change in a taste parameter i in a utility function. The ith argument in that function is not only the quantity of consumption of good i but a combination of the quantity consumed of good i and a taste parameter for good i. Altering tastes in the utility function by changing the taste parameter they call a "disembodied taste change".

We will follow Fisher et al. (1972) and define utility as a function of consumption and taste parameters. To fix ideas, let $U(\mathbf{q}, \varphi)$ represent the utility of the consumer obtained by consumption bundle $\mathbf{q}$ under tastes φ. The taste parameter φ is a vector of taste parameters that shift preferences around over time. The consumer does not choose φ, rather it changes exogenously. Under preferences that change over time, the money metric function becomes:

$$C(\mathbf{q}_0, \varphi, \mathbf{p}) = \min_{\mathbf{q}} \{\mathbf{p}.\mathbf{q} : U(\mathbf{q}, \varphi) = U(\mathbf{q}_0, \varphi)\} \tag{4}$$

Using this money metric function, defining a meaningful cost-of-living concept when preferences change over time becomes somewhat tricky. The traditional cost-of-living index compares budgets so that the consumer can obtain two different baskets under different prices, where she is "indifferent" between the two baskets. We will keep with the traditional usage of the word "indifferent" to only be applied as a concept *within* a utility surface, i.e. " indifferent" means being on the same indifference curve within that surface. When the utility surface changes between two periods, being "indifferent" can only be used as a concept when referring to a fixed utility surface. However, it remains possible to define a cost-of living concept under changing preferences.

Imagine two periods, where $(\mathbf{p_1}, \varphi_1)$ are the prices and tastes of period one and $(\mathbf{p_2}, \varphi_2)$ are the prices and tastes of period two. The consumption bundle $\mathbf{q}_0$ now has two indifference curves that pass through, $U(\mathbf{q}_0, \varphi_1)$ and $U(\mathbf{q}_0, \varphi_2)$. Under ordinal preferences, both levels of utility are incomparable.[3] They occur under different tastes. Three different cost of living concepts can now be defined. The first one using

In both period's the man's utility function is determined only up to a monotonic transformation; how can we possibly know whether the level of true utility (whatever that may mean) corresponding to a given indifference curve is the same in both periods? The man's efficiency as a pleasure-making machine may have changed without changing his tastes."

[3] 'Under ordinal preferences'is important here. One could develop a cardinal theory of utility where taste shocks shift the cardinal utility around and both utilities do become comparable. We do not go that route.

period one preferences only, the second one using period two preferences only and the third one using both preferences.

In the presence of taste changes, a family of cost-of-living indexes that encompasses all three concepts can be defined as follows.

$$P_N(\mathbf{q_0}, \varphi_1, \varphi_2, \mathbf{p_2}, \mathbf{p_1}) = \frac{C(\mathbf{q_0}, \varphi_2, \mathbf{p_2})}{C(\mathbf{q_0}, \varphi_1, \mathbf{p_1})} \tag{5}$$

The family is indexed by a consumption bundle, two price vectors and two taste parameters with (p_1, φ_1) the prices and taste of period one and (p_2, φ_2) the prices and tastes of period two. Now minimum expenditures needed under different price vectors can be established under period 1 preferences, under period 2 preferences and under both period preferences. This leads one to define three different concepts of cost-of-living, which have different meanings.

The first concept uses period one preferences and is defined as $P_N(\mathbf{q_0}, \varphi_1, \varphi_1, \mathbf{p_2}, \mathbf{p_1})$.

Using $P_N(\mathbf{q_0}, \varphi_1, \varphi_1, \mathbf{p_2}, \mathbf{p_1})$, the consumer with tastes φ_1 is indifferent, *under period 1 preferences* between a budget to spend $P_N(\mathbf{q_0}, \varphi_1, \varphi_1, \mathbf{p_2}, \mathbf{p_1})C(\mathbf{q_0}, \varphi_1, \mathbf{p_1})$ under the price vector $\mathbf{p_2}$ or having a budget to spend $C(\mathbf{q_0}, \varphi_1, \mathbf{p_1})$ under the price vector $\mathbf{p_1}$. This concept compares the expenditures needed under the first period's preferences to be indifferent between both periods price vectors. It is a standard cost-of-living concept under fixed preferences. Now note however, the consumer, under changing tastes, will be faced with different preferences at the same time she is faced with a different price vector (price vector $\mathbf{p_2}$ occurs at a time when she has tastes φ_2). So being compensated by this cost-of-living index does not take into account the preference shift.

Similarly, the second concept uses period two preferences. Using, $P_N(\mathbf{q_0}, \varphi_2, \varphi_2, \mathbf{p_2}, \mathbf{p_1})$, the consumer with tastes φ_2 is indifferent between having available a budget to spend $P_N(\mathbf{q_0}, \varphi_2, \varphi_2, \mathbf{p_2}, \mathbf{p_1})C(\mathbf{q_0}, \varphi_2, \mathbf{p_1})$ under the price vector $\mathbf{p_2}$ or having a budget to spend $C(\mathbf{q_0}, \varphi_2, \mathbf{p_1})$ under the price vector $\mathbf{p_1}$. This concept is similar as the one above. This concept compares the budgets needed under the second period's preferences to be indifferent between both periods price vectors. It again ignores the fact that the consumer is faced with different preferences at the same time she is faced with a different price vector (now price vector $\mathbf{p_1}$ occurs at a time when she has tastes φ_1 and not φ_2).

What about the third concept $P_N(\mathbf{q_0}, \varphi_1, \varphi_2, \mathbf{p_2}, \mathbf{p_1})$, when tastes are different, i.e. φ_1 and φ_2 are different? Note that now it would be wrong to say that the consumer is indifferent between a budget $P_N(\mathbf{q_0}, \varphi_1, \varphi_2, \mathbf{p_2}, \mathbf{p_1})C(\mathbf{q_0}, \varphi_1, \mathbf{p_1})$ under the price vector $\mathbf{p_2}$ or having a budget to spend $C(\mathbf{q_0}, \varphi_1, \mathbf{p_1})$ under the price vector $\mathbf{p_1}$, because now the tastes of the consumer have shifted from φ_1 to φ_2. The concept of indifference does not apply here. However $P_N(\mathbf{q_0}, \varphi_1, \varphi_2, \mathbf{p_2}, \mathbf{p_1})$ is still a usefull concept, especially when measured at $\mathbf{q}_0 = \mathbf{q}_1$, with $\mathbf{q}_1$ being the optimal consumption basket when faced with prices $\mathbf{p_1}$ and tastes φ_1. What does $P_N(\mathbf{q_1}, \varphi_1, \varphi_2, \mathbf{p_2}, \mathbf{p_1})$ mean? It is defined as, $\frac{C(\mathbf{q_1}, \varphi_2, \mathbf{p_2})}{C(\mathbf{q_1}, \varphi_1, \mathbf{p_1})}$.

It defines the monetary compensation needed to allow the consumer, faced with a new price vector $\mathbf{p_2}$ and new tastes φ_2, to obtain a level of utility that goes through the base period consumption bundle (that at an earlier time was optimal at the then prevailing prices and tastes). One could imagine a benevolent planner who has the power to change the budget of consumers but is faced with uncontrollable price and tastes changes. To us it is not immediately clear which of those three concepts the planner would use.

Otherwise said, under changing tastes, consumers income can be compensated for price changes (and taste changes) referring through three different concepts. The compensation can refer to the old preferences so that under those preferences the consumer would have been equally well of, i.e. as if the consumer tastes didn't change. The compensation can refer to the new preferences so that under those new preferences the consumer would be equally well under both price vectors. Or the compensation refers to both period preferences.

The third concept uses both periods preferences, which follows Basmann et al. (1984)[4] and Balk (1989) and defines a cost-of-living index between a base period and a current period by comparing the budgets needed in both periods to reach the now different indifference curves that go through some fixed (base period) bundle of goods.

Balk (1989) introduces the term *'equally well off'* in a world of changing preferences. Under changing preferences, 'equally well off' is defined as being on indifference curves, in the two periods, that go through some fixed basket of goods. So the concept of 'equally well of' is always a relative one, it needs a fixed basket of goods. Note that this doesn't mean, the consumer has the same level of utility. In a world of ordinal utility with shifting preferences, that becomes a meaningless statement. Being 'ındifferent' under fixed preferences has been replaced by being 'equally well off' under shifting preferences.

It is worth to rewrite the third concept cost-of-living index (measured at the first period optimal basket $\mathbf{q_1}$) as the result of two effects, a pure price compensation and a taste-change compensation.

$$P_N(\mathbf{q_1}, \varphi_1, \varphi_2, \mathbf{p_2}, \mathbf{p_1}) = \frac{C(\mathbf{q_1}, \varphi_2, \mathbf{p_2})}{C(\mathbf{q_1}, \varphi_2, \mathbf{p_1})} \frac{C(\mathbf{q_1}, \varphi_2, \mathbf{p_1})}{C(\mathbf{q_1}, \varphi_1, \mathbf{p_1})} \tag{6}$$

or equivalently

$$P_N(\mathbf{q_1}, \varphi_1, \varphi_2, \mathbf{p_2}, \mathbf{p_1}) = P_N(\mathbf{q_1}, \varphi_2, \varphi_2, \mathbf{p_2}, \mathbf{p_1}) \frac{C(\mathbf{q_1}, \varphi_2, \mathbf{p_1})}{C(\mathbf{q_1}, \varphi_1, \mathbf{p_1})} \tag{7}$$

The first factor $\frac{C(\mathbf{q_1}, \varphi_2, \mathbf{p_2})}{C(\mathbf{q_1}, \varphi_2, \mathbf{p_1})}$ is the traditional cost-of-living index and measures a pure price change effect under the second period preferences. It compares the expenditures under the second period preferences and the two different price vectors. However, such an index does not take into account the preference shift.

[4]The third concept is identical to what Basmann et al. (1984) calls $BCLI_2$, the basic-cost-of-living index. (see page 6 of Basmann et al. (1984).

The second factor $\frac{C(\mathbf{q_1},\varphi_2,\mathbf{p_1})}{C(\mathbf{q_1},\varphi_1,\mathbf{p_1})}$ measures the effect of the preference change. It measures the expenditure change which would be necessary if a pure preference change occurred while keeping the price vector constant and an indifference level was reached in the second period that passed through the first period's optimal basket.

2.2 Taste change bias

Why should economists care about preference changes? Clearly, the vast majority of the economics literature ignores them and assumes constant preferences over time. We think there are two good reasons to consider them. First, consumer preferences do change. So an assumption of taste changes brings theory closer to reality. Especially, the movements in micro-level price and expenditure data are hard to reconcile with being the result of only price and income changes. Taste changes can help in rationalizing such micro-data.

Second, changing tastes influence how we think about price change and therefore inflation measurement. Balk (1989) shows that a pure taste change (holding prices fixed) always lowers the cost of living (see corrolary 5 in Balk, 1989). The intuition for this result is as follows. If prices are fixed and taste change the consumer can still buy the same base period basket of goods and stay therefore on the indifference curve that goes through the base period basket. However as tastes have changed the curvature of the indifference curve going through the base period basket has changed, so you that a move along that curve under the constant prices that leads to cheaper but indifferent basket will be possible. So pure taste changes are always saving for the consumer.

Equivalently, the cost-of-living index under a pure taste change is given by

$$P_N(\mathbf{q_1},\varphi_1,\varphi_2,\mathbf{p_1},\mathbf{p_1}) = \frac{C(\mathbf{q_1},\varphi_2,\mathbf{p_1})}{C(\mathbf{q_1},\varphi_2,\mathbf{p_1})}\frac{C(\mathbf{q_1},\varphi_2,\mathbf{p_1})}{C(\mathbf{q_1},\varphi_1,\mathbf{p_1})} \tag{8}$$

or

$$P_N(\mathbf{q_1},\varphi_1,\varphi_2,\mathbf{p_1},\mathbf{p_1}) = \frac{C(\mathbf{q_1},\varphi_2,\mathbf{p_1})}{C(\mathbf{q_1},\varphi_1,\mathbf{p_1})} \tag{9}$$

Consider the base period basket $\mathbf{q_1}$ to be the optimal basket under prices $\mathbf{p_1}$ and tastes φ_1. Then we have that $C(\mathbf{q_1},\varphi_1,\mathbf{p_1}) = \mathbf{p_1}\mathbf{q_1}$. Let $\mathbf{q_*}$ be the optimal basket under prices $\mathbf{p_1}$ and tastes φ_2. Then we have that $C(\mathbf{q_1},\varphi_2,\mathbf{p_1}) = \mathbf{p_1}\mathbf{q_*}$. As $C(\mathbf{q_1},\varphi_2,\mathbf{p_1}) \leq \mathbf{p_1}\mathbf{q_1}$, we have that $\mathbf{p_1}\mathbf{q_*} \leq \mathbf{p_1}\mathbf{q_1}$ and hence that $P_N(\mathbf{q_1},\varphi_1,\varphi_2,\mathbf{p_1},\mathbf{p_1}) \leq 1$. Pure taste changes reduce cost-of-living. So we should expect that inflation measurement that doesn't take into account taste changes to be biased upward.

2.3 Expenditure change as the product of a pure price, taste and quantity index

Under consumer expenditure minimization the expenditure change between period 1 and period 2 can be written as the product of a pure price change index, a taste change index and a quantity index.

Let $\mathbf{q}_1$ and $\mathbf{q}_2$ be the optimal consumption baskets under period 1 and 2 tastes respectively. We have that

$$\frac{\mathbf{p}_2\mathbf{q}_2}{\mathbf{p}_1\mathbf{q}_1} = \frac{C(\mathbf{q_2}, \varphi_2, \mathbf{p_2})}{C(\mathbf{q_1}, \varphi_1, \mathbf{p_1})} \tag{10}$$

which can be rewritten as:

$$\frac{\mathbf{p}_2\mathbf{q}_2}{\mathbf{p}_1\mathbf{q}_1} == \frac{C(\mathbf{q_1}, \varphi_2, \mathbf{p_2})}{C(\mathbf{q_1}, \varphi_2, \mathbf{p_1})} \frac{C(\mathbf{q_1}, \varphi_2, \mathbf{p_1})}{C(\mathbf{q_1}, \varphi_1, \mathbf{p_1})} \frac{C(\mathbf{q_2}, \varphi_2, \mathbf{p_2})}{C(\mathbf{q_1}, \varphi_2, \mathbf{p_2})} \tag{11}$$

where the first term measures the effect on expenditure of a pure price change from $\mathbf{p_1}$ to $\mathbf{p_2}$ (holding tastes and quantity constant), the second a pure taste change from φ_1 to φ_2 and the third a pure quantity change from $\mathbf{q_1}$ to $\mathbf{q_2}$. or

$$\frac{\mathbf{p}_2\mathbf{q}_2}{\mathbf{p}_1\mathbf{q}_1} = P.T.Q \tag{12}$$

where the cost of living index is the product of the pure price change and the pure taste change $P_N = P.T$.

2.4 Utility, demand and an exact cost-of-living index

To calculate the cost-of-living index defined above one needs to model consumers' choices and make a functional assumption about how consumers form their utility. We model consumers' optimization problem using the nested constant elasticity of substitution system. This choice is motivated by both theoretical considerations and empirical tractability. The consensus in the literature is that the index formula derived from this framework could be of practical use for index calculation to statistical agencies. Its empirical application is however still limited. [5]

The nested constant elasticity of substitution framework is a prominent tool in international trade models because it allows for flexible substitution patterns. In particular, it allows for the elasticity of substitution between varieties within one product group to be different from the elasticity of substitution across product groups. The applied estimation strategy therefore is an upper level Cobb-Douglas demand

[5]"Effective with the release of CPI data for January 2015 on February 26, 2015, the Bureau of Labor Statistics will begin quarterly revisions of the Chained Consumer Price Index for All Urban Consumers (C-CPI-U). In addition, a Constant Elasticity of Substitution (CES) formula will replace the geometric mean formula for the calculation of Initial and Interim C-CPI-U indexes." See http://www.bls.gov/cpi/

system across product groups with a nested lower level CES demand system across varieties within one product group. The upper level Cobb-Douglas assumption implies constant product group level expenditure shares. Therefore, we can assume that firms supplying products belonging to different products do not strategically interact with each other. Further, the CES structure at the product group level implies strategic interaction between firms supplying products of the same product group.

We assume consumer utility at time t, U_t, is a Cobb-Douglas aggregate of CES-subutilities U_{gt} of product groups g, with $g \in G$.

$$U_t = \prod_{g \in G} U_{gt}^{\alpha_g} \quad with \quad \sum_{g \in G} \alpha_g = 1 \tag{13}$$

with

$$U_{gt} = \Big[\sum_{i \in I_g} (\varphi_{igt} c_{igt})^{\frac{\sigma_g - 1}{\sigma_g}} \Big]^{\frac{\sigma_g}{\sigma_g - 1}} \tag{14}$$

and normalization factor (for every g)

$$\prod_{i \in I_g} \varphi_{igt} = 1 \tag{15}$$

where c_{igt} is consumption of variety i in product group g at time t, and I_g is the set of all varieties in product group g. The elasticity of substitution σ_g determines the substitutability between varieties within one product group. It is allowed to differ across product groups.

Importantly, the parameters φ_{igt} measure the taste (or subjective quality as experienced by the consumer) for variety i in product group g. The taste parameters have a subscript t and are therefore allowed to change over time. The normalization factor guarantees uniqueness of the mapping of taste parameters and consumption to utility. Otherwise, in its abscence, due to the CES structure, a homeogenous increase of all φ_{igt} would simply be a relabelling of utility curves with no consequences for consumption behaviour.

To gain some intuition, in scanner data, items are identified by their universall product code (UPC). The UPC uniquely identifies an item, even minor changes such as packaging leads producers to marks the product as different, i.e. having a different UPC (mainly for stocking and bookkeeping reasons). So here variety i (or item i) can be defined as a UPC. An example, "all purpose cleaner" and "ice cream" are product groups (indexed by g), Mister proper 1 liter and 1 liter Dreyer vanilla ice cream are varieties (i.e UPC's indexed by i). The substitution elasticities within "all purpose cleaner" and within "ice cream" might be different.

Note that variation in taste is a different concept than quality change. Quality change is well defined in the price index literature. It generally coincides with the introduction of new varieties of a product or in product changes. Say the introduction of a new model iphone. In other words, a quality change alters some measurable attributes of a product.

Taste changes defined here are changes in the experienced utility of the consumer of an item whose characteristics remain unaltered. Such changes might occur purely exogenously or endogenously through marketing or media or other influence. As we use the identical set of UPC's over time in the empirical part, we have no quality change. Generally when firms change the characteristics of an item (even minor product packaging changes) the UPC changes (and effectively a new item is introduced).

The consumer is price taker, i.e. maximizes utility (or minimizes costs) given prices. Utility maximization (or Cost-minimization) of the consumer implies the following demand for variety i in product group g (see Appendix A):

$$c_{igt} = \varphi_{igt}^{\sigma g-1} p_{igt}^{-\sigma_g} P_{gt}^{\sigma g-1} E_{gt} \tag{16}$$

where p_{igt} is the price of variety i and P_{gt} is the CES price aggregate for product category g:

$$P_{gt} = P_g(\mathbf{p_{gt}}, \varphi_{\mathbf{gt}}) = \Big[\sum_{i\in I_g} (\frac{p_{igt}}{\varphi_{igt}})^{1-\sigma_g}\Big]^{\frac{1}{1-\sigma_g}} \tag{17}$$

and $\mathbf{p_{gt}}$ is the price vector of items in product group g, φ_{gt} is the taste vector of items in product group g and E_{gt} is total expenditure on product group g.

As the subutility U_{gt} of each product group is a CES aggregate, it is well known that its exact price index is a Sato-Vartia aggregate. See Vartia, 1976 and Sato, 1976.

We have for product group g,

$$\frac{P_{gt}}{P_{gt-1}} = \prod_{i\in I_g} (\frac{p_{igt}}{p_{igt-1}})^{w_{igt}} (\frac{\varphi_{igt-1}}{\varphi_{igt}})^{w_{igt}} \tag{18}$$

and log-change weights w_{igt} which are defined as,

$$w_{igt} = \frac{f(s_{igt}, s_{igt-1})}{\sum_{i\in I_g} f(s_{igt}, s_{igt-1})} \tag{19}$$

with $s_{igt} = p_{igt}c_{igt}/E_{gt}$ the share of expenditure of UPC i in product group g, and using the log-change function f,

$$f(y, x) = \frac{y - x}{\ln y - \ln x} \tag{20}$$

and for $y = x$ f is defined as,

$$f(x, x) = x \tag{21}$$

Importantly, under the assumption of varying tastes, the exact price index of product group g will vary, not only with prices, but also with variations in taste over time. We call $\varphi_{igt-1}/\varphi_{igt}$ taste shocks.

We call (18), a taste shock adjusted Sato-Vartia price index. It is equal to the standard Sato-Vartia index multiplied by a weighted average of taste shocks.

In Appendix C we show that the taste shocks of individual products can be shown to be a function of prices, expenditure shares and the elasticity of substitution,

$$\varphi_{igt-1}/\varphi_{igt} = \Big[\frac{p_{igt-1}}{\prod p_{igt-1}^{(1/N)}}/\Big[\frac{s_{igt-1}}{\prod s_{it-1}^{1/N}}\Big]^{\frac{1}{1-\sigma_g}}\Big]/\Big[\frac{p_{igt}}{\prod p_{igt}^{(1/N)}}/\Big[\frac{s_{igt}}{\prod s_{it}^{1/N}}\Big]^{\frac{1}{1-\sigma_g}}\Big] \tag{22}$$

where N is the number of UPC's in a product group.

Where prices and expenditures shares are observed, the elasticity of substitution is not. Measuring therefore the impact of taste shocks on our exact price index requires us to obtain an estimate of the elasticity of substitution for every product group. Below we show how one we can derive an estimate of the elasticity of substitution σ_g using scanner data.

Finally, aggregating over product groups, one can derive an exact cost-of-living index between period t-1 and t.[6]

$$P_N(\mathbf{q_{t-1}}, \varphi_{t-1}, \varphi_t, \mathbf{p_t}, \mathbf{p_t}) = \frac{U(\mathbf{q_{t-1}}, \varphi_t)}{U(\mathbf{q_{t-1}}, \boldsymbol{\varphi_{t-1}})} \prod_{g \in G} (\frac{P_{gt}}{P_{gt-1}})^{\alpha_g} \tag{23}$$

2.5 Formulae for the pure price index, taste change index and quantity index

In the Appendix we derive the different formula for the pure price index, the taste change index and quantity index at the product group and aggregate level. The cost-of living index is simply the product of the pure price index and the pure taste index

The pure price index at the product group level is a Sato-Vartia index:

$$SAVAg = \prod_{i \in I_g} (\frac{p_{igt}}{p_{igt-1}})^{w_{igt}} \tag{24}$$

The taste change index at the product group level is:

$$TCIg = \frac{U_{gt}(\mathbf{q_1}, \varphi_2)}{U_{gt-1}((\mathbf{q_1}, \varphi_1))} \prod_{i \in I_g} (\frac{\varphi_{igt-1}}{\varphi_{igt}})^{w_{igt}} = \frac{\Big[\sum_{i \in I_g} (\varphi_{igt} c_{igt-1})^{\frac{\sigma_g - 1}{\sigma_g}}\Big]^{\frac{\sigma_g}{\sigma_g - 1}}}{\Big[\sum_{i \in I_g} (\varphi_{igt-1} c_{igt-1})^{\frac{\sigma_g - 1}{\sigma_g}}\Big]^{\frac{\sigma_g}{\sigma_g - 1}}} \prod_{i \in I_g} (\frac{\varphi_{igt-1}}{\varphi_{igt}})^{w_{igt}} \tag{25}$$

The cost-of-living index at the product group level is $SAVATAg$ defined as the pure price index multiplied by the taste change index, i.e. $SAVAg * TCIg$. Note that our cost-of-living index differs from the common goods price index as in Redding and Weinstein (2016) with the utility correction $\frac{U_{gt}(\mathbf{q_1}, \varphi_2)}{U_{gt-1}((\mathbf{q_1}, \varphi_1))}$. In Redding and Weinstein (2016) demand shocks do not affect utility directly.

The quantity index at the product group level is,

[6]The unobserved α_g do not pose a problem, as it can be readily shown that they are equal to the expenditure share of the product group in total consumption.

$$Qg = \frac{U_{gt}(\mathbf{q_2}, \varphi_2)}{U_{gt-1}(\mathbf{q_1}, \varphi_2))} = \frac{\left[\sum_{i \in I_g} (\varphi_{igt} c_{igt})^{\frac{\sigma_g - 1}{\sigma_g}}\right]^{\frac{\sigma_g}{\sigma_g - 1}}}{\left[\sum_{i \in I_g} (\varphi_{igt} c_{igt-1})^{\frac{\sigma_g - 1}{\sigma_g}}\right]^{\frac{\sigma_g}{\sigma_g - 1}}} \tag{26}$$

The pure price index at the country level is:

$$SAVAc = \prod_{g \in G} \left[\prod_{i \in I_g} (\frac{p_{igt}}{p_{igt-1}})^{w_{igt}} \right]^{\alpha_g} \tag{27}$$

The taste change index at the country level is:

$$TCIc = \frac{\prod_{g \in G} \left[U_{gt}(\mathbf{q_1}, \varphi_2)\right]^{\alpha_g}}{\prod_{g \in G} \left[U_{gt-1}(\mathbf{q_1}, \varphi_1)\right]^{\alpha_g}} \prod_{g \in G} \left[\prod_{i \in I_g} (\frac{\varphi_{igt-1}}{\varphi_{igt}})^{w_{igt}} \right]^{\alpha_g} = \tag{28}$$

$$= \frac{\prod_{g \in G} \left[\left[\sum_{i \in I_g} (\varphi_{igt} c_{igt-1})^{\frac{\sigma_g - 1}{\sigma_g}}\right]^{\frac{\sigma_g}{\sigma_g - 1}}\right]^{\alpha_g}}{\prod_{g \in G} \left[\left[\sum_{i \in I_g} (\varphi_{igt-1} c_{igt-1})^{\frac{\sigma_g - 1}{\sigma_g}}\right]^{\frac{\sigma_g}{\sigma_g - 1}}\right]^{\alpha_g}} \prod_{g \in G} \left[\prod_{i \in I_g} (\frac{\varphi_{igt-1}}{\varphi_{igt}})^{w_{igt}} \right]^{\alpha_g} \tag{29}$$

The cost-of-living index at the country level is $SAVATAc$ defined as $SAVAc * TCIc$.

The quantity index at the country level is:

$$Qc = \prod_{g \in G} Qg^{\alpha_g} \tag{30}$$

3 The data

To construct our exact cost-of-living index, We use a large scanner dataset provided by the marketing research firm AC Nielsen. The data contains price and quantity observations for a large set of stock keeping units (SKU's) over the period 2009-2010 for a set of 10 countries (Austria, Belgium, Germany, Spain, France Greece, Ireland, Italy, Netherlands and Portugal). A stock keeping unit is a uniquely identified item (brand, product name, package size, content) with a unique Universal Product Code (UPC).

To construct our data, AC Nielsen has sorted, for each country separately, individual stores into homogeneous store categories.

The observations available to us consist of monthly aggregate price and quantity couples for each individual stock keeping unit at the country-store type level. A "variety" or "item" in this paper means a "country-store-type-stock-keeping unit triple. So the price of an item is the average monthly price of a particular stock keeping unit in a particular store type within a country.

A 'product group' is the collection of have many 'varieties'. A product group is defined as a country-product pair. Using this definition we end up covering 338 distinct product-groups (e.g. ice cream in Austria is one product group but ice cream in The Netherlands is defined as a different product group). Our dataset covers 15844 items.

4 Estimating the elasticity of substitution

Our strategy in obtaining an estimate of the elasticity of substitution follows closely the method developed in Broda and Weinstein (2006) and Feenstra (2004). We first discuss develop a model of supply, which we then combine with our demand function

4.1 Supply

We assume each variety i is produced by a one-product monopolistic competitive firm, so the index i denotes both the firm and the variety. Within a product group we assume Bertrand competition, i.e. each firm chooses its price to maximize total firm profit. Importantly, the firm internalizes the impact of its price change on the product group price aggregate, P_{gt}, but ignores prices of other product groups.

Assume the firm faces variable cost shocks z_{igt} and total variable cost V_{igt}, such that

$$V_{igt}(c_{igt}) = z_{igt} \cdot c_{igt}^{1+\delta_g} \tag{31}$$

We assume that firms within the same product group face the same slope of the variable cost curve.

The producer's profit maximization problem (allowing for fixed cost H_i) is

$$\Pi_{igt} = p_{igt} \cdot c_{igt} - V_{igt}(c_{igt}) - H_i \tag{32}$$

such that

$$c_{igt} = \varphi_{igt}^{\sigma g-1} p_{igt}^{-\sigma_g} P_{gt}^{\sigma g-1} E_{gt} \tag{33}$$

The first order condition is:

$$\frac{\partial \Pi_{igt}}{\partial p_{igt}} = 0$$

Solving the above first order condition, we get the following expression for the supply curve of the producer (derivation in the Appendix B):

$$p_{igt} = \mu_{igt} z_{igt} (1+\delta_g) c_{igt}^{\delta_g} \tag{34}$$

where μ_{igt} is the markup of the producer:

$$\mu_{igt} = \frac{-\sigma_g + (\sigma_g - 1) \cdot \epsilon_{igt}}{(\sigma_g - 1) \cdot (\epsilon_{igt} - 1)} \tag{35}$$

and ϵ_{igt} denotes the elasticity of the price level of product group g with respect to the producer's own price of UPC i. This elasticity can be shown to be equal to the expenditure share s_{igt}.

4.2 Structural estimation

The estimation procedure of σ_g is based on the identification strategy presented in Broda and Weinstein (2006), Feenstra, 1994. Identification is reached by assuming that the slope of the demand and supply curves, σ_g, δ_g, is constant across UPCs within a product group and over time but the intercepts are allowed to vary across varieties and time. Within product group taste shifts are assumed orthogonal to within product group supply shocks.

To define the orthogonality conditions our starting point is the expression for the UPC level expenditure share, equation 36 (see Appendix A for derivation) and firms pricing rule, equation 34.

$$s_{igt} = \frac{(\frac{p_{igt}}{\varphi_{igt}})^{1-\sigma_g}}{P_{gt}^{1-\sigma_g}} \tag{36}$$

As a first step, we double-difference the log of equation (36) first in time, then we take difference from the largest UPC within each product group (Note that the largest UPC is taken as the UPC having the largest expenditure share over the whole observation period). By double differencing, we eliminate all demand shocks that are common within a product group. This gives us an expression for the relative UPC demand:

$$\Delta^{kt} \ln s_{igt} = (1 - \sigma_g)\Delta^{kt} \ln p_{igt} + \omega_{gt} \tag{37}$$

where Δ^{kt} defines $\Delta^k \ln s_{igt} = \Delta \ln s_{igt} - \Delta \ln s_{kgt}$.

As a next step, we take firm's pricing rule, equation 34. We substitute for the marginal cost, using () and apply that $C_{igt}^{\delta_g} = \frac{s_{igt}}{p_{igt}}$. We double difference the log of the expression after performing these substitutions both in time and relative to the largest UPC. Thus we derive an expression for the relative UPC supply.

$$\Delta^{k,t} \ln p_{gt} = \frac{\delta_g}{1+\delta_g}\Delta^{k,t} \ln s_{igt} + \frac{1}{1+\delta_g}\Delta^{k,t}\kappa_{gt} \tag{38}$$

As discussed above, the orthogonality assumption of the idiosyncratic demand and supply shocks κ_{gt} and ω_{gt} determines our orthogonality condition.

$$G(\beta_g) = \mathbf{E_t}\left[\omega_{\mathbf{gt}}\kappa_{\mathbf{gt}}\right] = 0 \tag{39}$$

where $\beta_g = \binom{\sigma_g}{\delta_{gt}}$. We stack all the moment conditions for varieties within a product group to form a GMM objective function:

$$\hat{\beta}_g = \underset{\beta_g}{\operatorname{argmin}}\, G^\star(\beta_g)' W G^\star(\beta_g)\ \forall g \tag{40}$$

where W is a positive definite weighting matrix. The identifying assumption relies on both the orthogonality assumption in 39 and the heteroscedastic variances of the double differenced demand and supply shocks across UPCs.

5 Results

5.1 Elasticity of substitution

Using the estimation strategy discussed above, we estimate elasticity of substitution parameters, σ_g, for 338 product groups. For 7 we do not get convergence and so we are left with 331 estimated parameters. Table 1 shows the distribution of the estimated 331 elasticity of substitution parameters. The results show that varieties within product groups are imperfect substitutes, moreover, high degree of consumer substitution takes place within most of the product groups studied, and that there is large variation in the elasticity of substitution between product groups.

Across product groups σ_g ranges from 2.3 at the 5th percentile to 28 at the 95th percentile, with a median elasticity of 4.1. This can be interpreted that at the median a one percent price increase of a particular item causes the sales of that item to drop by 4.1 per cent. To assess how our results compare to similar estimates in the literature, ideally we would like to consider studies that used similar data sets, possibly for the same countries. However, the set of such studies is limited. One exception is the paper by Hottman et al., 2014 who use the Nielsen HomeScan database for the US to estimate elasticity of substitution both within and between multiproduct firms for the same product group. Because our model assumes that each firm produces a single variety, we compare our estimates to their results for the between firm elasticity of substitution. The median estimate obtained in Hottman et al., 2014 is 3.9 which is very close to our estimate of 4.1. The estimated range for σ_f in Hottman et al., 2014, which lies between 2.6 at the 10th percentile and 7.3 at the 90th percentile also resembles our estimates, 2.5 at the 10th percentile and 14 at the 90th percentile.

The choice of the function to model consumers' utility has important consequences for our estimates. The larger the substitution taking place between individual items, the more sensitive is the price index to relative price changes. The Cobb-Douglas utility function is the limit case of the CES function when $\sigma \to 1$, and it is the Jevons index (geometric Laspeyres price index) that derives from the Cobb-Douglas utility function. In the other limit case, the CES utility becomes the Leontief utility function when $\sigma \to 0$. In the latter case the price index that derives from the Leontief utility function is the Laspeyres price index. It is therefore interesting to test whether the assumption underlying the CES utility function $\sigma_g > 0, \sigma \neq 1$ is an accurate description of consumers' substitution patterns. Therefore, we test the null hypothesis $H_0 : \sigma_g = 0$. Using a standard t-test and a critical value of 1.96, for the majority of the cases

Table 1: Distribution, σ_g

Percentile	σ_g
p1	2.0
p5	2.3
p10	2.5
p25	3.1
p50	4.1
p75	6.3
p90	14
p95	28
p99	152

the elasticity parameter is significantly different from 0, and the null could not be rejected for 44 product groups from a total of 331.

5.2 Product group price indexes

In this section we analyze different product-group price indices. We pool the annual inflation estimates of 331 product groups to show the across product-group distribution of annual inflation. We compare the inflation measured by our cost-of living index SAVATAg which allows for taste changes with four other traditional price indexes which do not allow for taste changes: the SATO-VARTIA index (SAVAg), the Jevons index (JEVONS), the Fisher index (FISHER) and the Laspeyres index (LASPEYRES). The distribution of inflation measured by the different indexes is give in table 2.

Table 2: **Product group inflation measured by various indexes**
(y-on-y change in percentage using monthly data)

Index	**min**	**p10**	**p25**	**p50**	**p75**	**p90**	**max**	**mean**	**sd**
SAVATAg	-43.4	-9.4	-4.8	-1.8	0.5	3.2	41.2	-2.4	6.3
SAVAg	-28.8	-7.1	-3.4	-0.9	1.2	4.0	41.5	-1.1	5.6
JEVONS	-24.0	-5.8	-2.8	-0.6	1.3	3.6	42.8	-0.7	4.8
FISHER	-28.9	-7.1	-3.4	-0.9	1.2	4.0	41.5	-1.1	5.6
LASPEYRES	-27.0	-6.3	-2.9	-0.6	1.6	4.5	41.8	-0.5	5.6

There is a wide dispersion of inflation across product groups for all indexes. This is not surprising. Product groups are very narrowly defined and inflation can therefore be both largely negative or positive.

A few noteworthing observations are the following. First, the distribution of the Sato-Vartia index and the Fisher index are very similar. Second, expectedly, the mean of product group inflation measured by the Laspeyres index is around 0.6 percentage points higher than the mean of the Fisher index, attesting to the upward substitution bias of the Laspeyres index. However most noteworthy is the our SAVATAg index which allows for taste changes. Inflation measured at the product group level is on average 1.3 percentage points lower than the Fisher index. As indicated in our theoretical discussion, taste changes tend to lower measured inflation rates.

How much different, in percentage point terms, are the product group level inflation measured by the different indices from a superlative index such as the Fisher index? The answer is given in Table 3. Here, we subtract the indexes from the Fisher index. The difference between of the Fisher index with the Sato-Vartia index is on average zero with a standard deviation of 0.4 percentage points (mostly caused by some outlier product groups, as the tables indicates that for 50 percent of the product groups the difference is very small, between -0.02 and 0.01 percentage points.) The Jevons and Laspeyres index are clearly upward biased relative to the Fisher index. However, again most noteworthy, allowing for taste changes the SAVTAg index is on average 1.3 percentage points lower than the Fisher index, but with a large standard deviation of 3 percentage points, indicating that taste changes can be quite of different importance depending on the product group.

Finally we report the difference between inflation measured by SAVATAg and SAVAg which effectively measures the percentage change in cost-of-living purely due to taste changes (i.e. it measures the rate of change of TCIg), i.e the effect of the taste shocks. The median effect is -0.4 percentage points, but the mean effect is -1.3 percentage points and the standard deviation is large at 2.9 percentage points (again this is due to a few outlier product groups, for 50 percent of product groups taste changes reduce cost-of-living between 1.2 and 0.1 percentage points.)

Table 3: **Difference between Fisher and selected indexes (percentage points)**

variable	**min**	**p10**	**p25**	**p50**	**p75**	**p90**	**max**	**mean**	**sd**
FISHER-SAVATAg	-4.1	0.0	0.1	0.4	1.2	3.0	46.8	1.3	3.0
FISHER-SAVAg	-6.7	-0.09	-0.02	0.0	0.01	0.07	5.8	0.0	0.4
FISHER-JEVONS	-18.81	-3.3	-1.5	-0.2	0.9	2.3	21.6	-0.4	2.9
FISHER-LASPEYRES	-19.5	-1.5	-0.7	-0.3	-0.05	0.04	12.3	-0.5	1.2

Table 4: **Difference between SAVATAg and SAVAg (percentage points)**

variable	min	p10	p25	p50	p75	p90	max	mean	sd
SAVATAg-SAVAg	-42.0	-3.1	-1.2	-0.4	-0.1	0.0	2.2	-1.3	2.9

5.3 Country level price indices

In this section, we analyze the country level price indices : $\frac{U(\mathbf{q_{t-1}},\varphi_t)}{U(\mathbf{q_{t-1}},\varphi_{\mathbf{t-1}})}\prod_{g\in G}(\frac{P_{gt}}{P_{gt-1}})^{\alpha_g}$. This index is constructed by aggregating across product group price indexes.

Table 5 reports both the taste adjusted Sato-Vartia index at the national level (SAVATAc) and the Sato-Vartia index (SAVA). We report the distribution of the 12 months of annual inflation rates over the year 2010. We find that upon aggregation the national cost-of-living indexes measured by the taste adjusted Sato-Vartia index and the Sato-Vartia index are similarly volatile.

However, more importantly,for all 10 countries, the average rate of measured inflation is lower for the taste adjusted Sato-Vartia index than for the Sato-Vartia index. This result was expected. Pure taste changes lower the cost-of-living. The average reduction across countries in the inflation rate when allowing for taste changes is 1.1 percent.

6 Conclusion

We have shown that introducing preference shifts in a utility framework has important implications for cost-of-living measurement. The theoretical cost-of-living index under CES preferences is a taste adjusted Sato-Vartia index. Although the theoretical discussion of taste changes in the theory of price indexes goes back at least as far as Fisher and Shell (1972), actual practice of inflation measurement has lagged behind. This can be partly attributed to the large data requirements for estimating a theoretically consistent cost-of-living index, such as the taste adjusted Sato-Vartia index, as both prices and quantities consumed of a broad set of products and close substitutes are necessary.

However, the data requirements are fulfilled in the presence of barcode level data. One can then estimate the elasticity of substitution for a large set of product groups and use prices and market share jointly with the elasticity of substitution to measure the taste parameters of the utility surface of the consumer. This finally leads to a taste-adjusted Sato-Vartia index which can be used to measure cost-of-living.

Our empirical results are based on a very large barcode level dataset of consumer prices and expenditures across 311 product groups and ten countries. Comparing a taste-adjusted Sato-Vartia index with the traditional Sato-Vartia index (which is the theoretical cost-of-living index under fixed preferences) leads to an annual inflation that is on average 1.1 percentage points lower. The upward bias of ignoring

Table 5: National cost-of-living indexes

country	**index**	**min**	**mean**	**max**	**sd**
AT	SAVATAc	-3.6	-2.4	-1.4	0.8
	SAVAc	-2.0	-1.1	-0.2	0.7
BE	SAVATAc	-2.1	-1.0	-0.4	0.5
	SAVAc	-1.7	-0.5	0.1	0.5
DE	SAVATAc	-3.8	-2.1	0.2	1.3
	SAVAc	-2.7	-1.0	1.1	1.3
ES	SAVATAc	-3.2	-2.4	-1.2	0.7
	SAVAc	-2.0	-1.2	-0.2	0.6
FR	SAVATAc	-0.9	0.1	1.3	0.8
	SAVAc	-0.6	0.5	1.7	0.8
GR	SAVATAc	-5.4	-1.1	1.0	1.9
	SAVAc	-4.6	-0.2	1.8	2.0
IE	SAVATAc	-10.5	-7.6	-3.5	2.3
	SAVAc	-9.1	-6.6	-2.4	2.3
IT	SAVATAc	-3.5	-2.6	-1.5	0.6
	SAVAc	-2.9	-2.0	-1.1	0.6
NL	SAVATAc	-3.1	-0.3	1.5	1.7
	SAVAc	-2.1	0.4	2.0	1.5
PT	SAVATAc	0.0	1.1	1.8	0.5
	SAVAc	1.1	2.2	2.9	0.5

taste changes is therefore large. Our results, therefore point towards an important gap in cost-of-living measurement and a potential significant source of bias in traditional price indexes.

Appendices

A Demand

A.1 Consumer optimization

The consumer maximizes utility given budget E_t. The utility function is given by a Cobb-Douglas aggregate of CES sub-utilities,

$$U_t = \prod_{g \in G} U_{gt}^{\alpha_g} \quad with \quad \sum_{g \in G} \alpha_g = 1 \tag{41}$$

and

$$U_{gt} = \Big[\sum_{i \in I_g} (\varphi_{igt} c_{igt})^{\frac{\sigma_g - 1}{\sigma_g}} \Big]^{\frac{\sigma_g}{\sigma_g - 1}} \tag{42}$$

where φ_{igt} is the taste parameter of item i in product group g at time t.

Total expenditures are,

$$E_t = \sum_{g \in G} \sum_{i \in I_g} p_{igt} c_{igt} \tag{43}$$

The Lagrangian is

$$L = U_t - \lambda \Big[\sum_{g \in G} \sum_{i \in I_g} p_{igt} c_{igt} - E_t \Big] \tag{44}$$

First order Condition w.r.t. c_{igt} (use the chain rule)

$$-\lambda p_{igt} + \frac{\delta U_t}{\delta U_{gt}} . \frac{\delta U_{gt}}{\delta c_{igt}} = 0 \tag{45}$$

We have that

$$\frac{\delta U_t}{\delta U_{gt}} = \frac{\alpha_g \prod_{g \in G} U_{gt}^{\alpha_g}}{U_{gt}} \tag{46}$$

$$\frac{\delta U_{gt}}{\delta c_{igt}} = \varphi_{igt} \Big[\sum_{i \in I_g} (\varphi_{igt} c_{igt})^{\frac{\sigma_g - 1}{\sigma_g}} \Big]^{\frac{\sigma_g}{\sigma_g - 1} - 1} (\varphi_{igt} c_{igt})^{\frac{\sigma_g - 1}{\sigma_g} - 1} \tag{47}$$

The term (47) can be simplified to:

$$\frac{\delta U_{gt}}{\delta c_{igt}} = \varphi_{igt} \Big[\sum_{i \in I_g} (\varphi_{igt} c_{igt})^{\frac{\sigma_g - 1}{\sigma_g}} \Big]^{\frac{1}{\sigma_g - 1}} (\varphi_{igt} c_{igt})^{\frac{-1}{\sigma_g}} \tag{48}$$

A.2 Combining the F.O.C. for 2 items of the same product group

The F.O.C. of differents items of the same product group have the following term which are identical: $\frac{\delta U_t}{\delta U_{gt}}$

Combine the F.O.C. for item i and item j of the same product group:

$$\frac{\frac{\delta U_{gt}}{\delta c_{igt}}}{\frac{\delta U_{gt}}{\delta c_{jgt}}} = \frac{p_{igt}}{p_{jgt}} \tag{49}$$

$$\frac{\varphi_{igt}\left[\sum_{i\in I_g}(\varphi_{igt}c_{igt})^{\frac{\sigma_g-1}{\sigma_g}}\right]^{\frac{1}{\sigma_g-1}}(\varphi_{igt}c_{igt})^{\frac{-1}{\sigma_g}}}{\varphi_{jgt}\left[\sum_{i\in I_g}(\varphi_{igt}c_{igt})^{\frac{\sigma_g-1}{\sigma_g}}\right]^{\frac{1}{\sigma_g-1}}(\varphi_{jgt}C_{jgt})^{\frac{-1}{\sigma_g}}} = \frac{p_{igt}}{p_{jgt}} \tag{50}$$

The middle term cancels:

$$\frac{\varphi_{igt}(\varphi_{igt}C_{igt})^{\frac{-1}{\sigma_g}}}{\varphi_{jgt}(\varphi_{jgt}c_{jgt})^{\frac{-1}{\sigma_g}}} = \frac{p_{igt}}{p_{jgt}} \tag{51}$$

Combining factors:

$$(\frac{\varphi_{igt}}{\varphi_{jgt}})^{\frac{\sigma_g-1}{\sigma_g}}(\frac{c_{igt}}{c_{jgt}})^{\frac{-1}{\sigma_g}} = \frac{p_{igt}}{p_{jgt}} \tag{52}$$

Multiply both sides by $(\frac{p_{igt}}{p_{jgt}})^{\frac{-1}{\sigma_g}}$

$$(\frac{\varphi_{igt}}{\varphi_{jgt}})^{\frac{\sigma_g-1}{\sigma_g}}(\frac{p_{igt}c_{igt}}{p_{jgt}c_{jgt}})^{\frac{-1}{\sigma_g}} = \frac{p_{igt}}{p_{jgt}}^{\frac{\sigma_g-1}{\sigma_g}} \tag{53}$$

Do power $-\sigma_g$

$$(\frac{\varphi_{igt}}{\varphi_{jgt}})^{1-\sigma_g}(\frac{p_{igt}c_{igt}}{p_{jgt}c_{jgt}}) = (\frac{p_{igt}}{p_{jgt}})^{1-\sigma_g} \tag{54}$$

Denote total sales of the product group as $E_{gt} = \sum_{j\in I_g} p_{jgt}c_{jgt}$. Divide numerator and denominator by total sales of the product group E_{gt} and let $s_{igt} = \frac{p_{igt}c_{igt}}{E_{gt}}$ denote expenditure share of item i in product group g.

$$(\frac{\varphi_{igt}}{\varphi_{jgt}})^{1-\sigma_g}(\frac{s_{igt}}{s_{jgt}}) = (\frac{p_{igt}}{p_{jgt}})^{1-\sigma_g} \tag{55}$$

Take logs:

$$(1-\sigma_g)(\ln\varphi_{igt} - \ln\varphi_{jgt}) + \ln s_{igt} - \ln s_{jgt} = \tag{56}$$

$$(1-\sigma_g)(\ln p_{igt} - \ln p_{jgt}) \tag{57}$$

Take the same equation at time t-1 and take the time difference

$$(1-\sigma_g)(\Delta \ln \varphi_{igt} - \Delta \ln \varphi_{jgt}) + \Delta \ln s_{igt} - \Delta \ln s_{igt} = \tag{58}$$

$$(1-\sigma_g)(\Delta \ln p_{igt} - \Delta \ln p_{jgt}) \tag{59}$$

Define $\Delta^{i,t}$ as the across time, across UPC difference. You then can write the above as,

$$(1-\sigma_g)(\Delta^{i,t} \ln \varphi_{igt}) + \Delta^{i,t} \ln s_{igt} = \tag{60}$$

$$(1-\sigma_g)(\Delta^{i,t} \ln p_{igt}) \tag{61}$$

Or

$$\Delta^{i,t} \ln s_{igt} = (1-\sigma_g)(\Delta^{i,t} \ln p_{igt}) - (1-\sigma_g)(\Delta^{i,t} \ln \varphi_{igt}) \tag{62}$$

A.3 Demand for a particular item

The equation (54) can be used to derive the demand curve of the particular item i.

First rewrite (54) to isolate the spending on item j.

$$p_{jgt}c_{jgt} = (\frac{\varphi_{igt}}{\varphi_{jgt}})^{1-\sigma_g}(p_{igt}c_{igt})(\frac{p_{jgt}}{p_{igt}})^{1-\sigma_g} \tag{63}$$

Summing over all j in product group g.

$$E_{gt} = \sum_{j \in I_g} (\frac{\varphi_{igt}}{\varphi_{jgt}})^{1-\sigma_g}(p_{igt}c_{igt})(\frac{p_{jgt}}{p_{igt}})^{1-\sigma_g} \tag{64}$$

Rewrite this as:

$$E_{gt} = c_{igt}\varphi_{igt}^{1-\sigma_g} {p_{igt}}^{\sigma_g} \sum_{j \in I_g} (\frac{p_{jgt}}{\varphi_{jgt}})^{1-\sigma_g} \tag{65}$$

Define the exact price aggregate of product group g at time t:

$$P_{gt}(\varphi_{gt}) \equiv P_{gt} \equiv \Big[\sum_{j \in I_g} (\frac{p_{jgt}}{\varphi_{jgt}})^{1-\sigma_g}\Big]^{\frac{1}{1-\sigma_g}} \tag{66}$$

We will use the notation $P_{gt}(\varphi_{gt})$ when we want to stress the fact that P_{gt} depends on the taste shocks φ_{jgt}.

Then the total expenditure on all items of product group g can be written as:

$$E_{gt} = c_{igt}\varphi_{igt}^{1-\sigma_g} {p_{igt}}^{\sigma_g} P_{gt}^{1-\sigma_g} \tag{67}$$

Which gives the demand equation for item i

$$c_{igt} = \varphi_{igt}^{\sigma_g - 1} E_{gt} P_{gt}^{\sigma_g - 1} {p_{igt}}^{-\sigma_g} \tag{68}$$

A.4 Expenditure shares and price index elasticity w.r.t. price

A.4.1 Expenditure share of item i

Above we defined, the expenditure share of item i of product group g at time t, as a share of total spending on group g .

$$s_{igt} = \frac{p_{igt} c_{igt}}{E_{gt}} \tag{69}$$

Then we can use equation (67) which describes E_{gt}

$$s_{igt} = \frac{p_{igt} c_{igt}}{c_{igt} \varphi_{igt}^{1-\sigma_g} {p_{igt}}^{\sigma_g} P_{gt}^{1-\sigma_g}} \tag{70}$$

Simplify into:

$$s_{igt} = \frac{(\frac{p_{igt}}{\varphi_{igt}})^{1-\sigma_g}}{P_{gt}^{1-\sigma_g}} \tag{71}$$

or using the exact price index of group g:

$$s_{igt} = \frac{(\frac{p_{igt}}{\varphi_{igt}})^{1-\sigma_g}}{\left[\sum_{j \in I_g} (\frac{p_{jgt}}{\varphi_{jgt}})^{1-\sigma_g}\right]} \tag{72}$$

A.4.2 Elasticity of the price index of product group g w.r.t the price of item i

Start from the definition of the exact price index of product group g :

$$P_{gt} = \left[\sum_{j \in I_g} (\frac{p_{jgt}}{\varphi_{jgt}})^{1-\sigma_g}\right]^{\frac{1}{1-\sigma_g}} \tag{73}$$

Taking the first derivative of the above equation, then a few lines of algebra shows that the elasticity of the price index of product group g w.r.t. price of UPC i is:

$$\frac{dP_{gt}}{dp_{igt}} \frac{p_{igt}}{P_{gt}} = \frac{(\frac{p_{igt}}{\varphi_{igt}})^{1-\sigma_g}}{\left[\sum_{j \in I_g} (\frac{p_{jgt}}{\varphi_{jgt}})^{1-\sigma_g}\right]} \tag{74}$$

which is, as show above, equal to the expenditure share of item i in product group g, s_{igt}.

A.5 First derivative of demand w.r.t. own price

The demand equation for item i of product group g was derived above:

$$c_{igt} = \varphi_{igt}^{\sigma_g - 1} E_{gt} P_{gt}^{\sigma_g - 1} p_{igt}{}^{-\sigma_g} \tag{75}$$

We consider that changing the price of item i has negligable impact on total group expenditure E_{gt} The first derivative own demand w.r.t.own price is then,

$$\frac{dc_{igt}}{dp_{igt}} = -\sigma_g \frac{c_{igt}}{p_{igt}} + (\sigma_g - 1) \frac{\partial P_{gt}}{\partial p_{igt}} \frac{c_{igt}}{P_{gt}} \tag{76}$$

or

$$\frac{dc_{igt}}{dp_{igt}} = -\sigma_g \frac{c_{igt}}{p_{igt}} + (\sigma_g - 1) \frac{\partial P_{gt}}{\partial p_{igt}} \frac{p_{igt}}{P_{gt}} \frac{c_{igt}}{p_{igt}} \tag{77}$$

or using the equality of expenditure share and price elasticity

$$\frac{dc_{igt}}{dp_{igt}} = -\sigma_g \frac{c_{igt}}{p_{igt}} + (\sigma_g - 1) s_{igt} \frac{c_{igt}}{p_{igt}} \tag{78}$$

B The Supply equation

B.1 Profit maximization and the markup

We assume each item i is produced by a one-product monopolistic competitive firm, so the index i denotes both the firm and the item. Within a product group we assume Bertrand competition, i.e. each firm chooses its price to maximize total firm profit. Importantly, the firm internalizes the impact of its price change on the product group price aggregate, P_{gt}, but ignores prices of other product groups.

Assume the firm faces variable cost shocks z_{igt} and total variable cost V_{igt}, such that

$$V_{igt}(c_{igt}) = z_{igt} \cdot c_{igt}^{1+\delta_g} \tag{79}$$

We assume that firms within the same product group face the same slope of the variable cost curve. The producer's profit maximization problem (allowing for fixed cost H_i) is

$$\Pi_{igt} = p_{igt} \cdot c_{igt} - V_{igt}(c_{igt}) - H_i \tag{80}$$

such that

$$c_{igt} = \varphi_{igt}^{\sigma g - 1} p_{igt}^{-\sigma_g} P_{gt}^{\sigma g - 1} E_{gt} \tag{81}$$

The F.O.C. of proft maximization is ,

$$c_{igt} + p_{igt}\frac{\partial c_{igt}}{\partial p_{igt}} - \frac{\partial V_{igt}(c_{igt})}{\partial c_{igt}}\frac{\partial c_{igt}}{\partial p_{igt}} = 0 \tag{82}$$

Now substitute using equation (78)

$$c_{igt} + p_{igt}(-\sigma_g)\frac{c_{igt}}{p_{igt}} \tag{83}$$

$$+p_{igt}(\sigma_g - 1)s_{igt}\frac{c_{igt}}{p_{igt}} \tag{84}$$

$$-\frac{\partial V_{igt}(c_{igt})}{\partial c_{igt}}(-\sigma_g)\frac{c_{igt}}{p_{igt}} \tag{85}$$

$$-\frac{\partial V_{igt}(c_{igt})}{\partial c_{igt}}(\sigma_g - 1)s_{igt}\frac{c_{igt}}{p_{igt}} = 0 \tag{86}$$

Simplify and divide by c_{igt}

$$1 + (-\sigma_g) \tag{87}$$

$$+(\sigma_g - 1)s_{igt} \tag{88}$$

$$-\frac{\partial V_{igt}(c_{igt})}{\partial c_{igt}}(-\sigma_g)\frac{1}{p_{igt}} \tag{89}$$

$$-\frac{\partial V_{igt}(c_{igt})}{\partial c_{igt}}(\sigma_g - 1)s_{igt}\frac{1}{p_{igt}} = 0 \tag{90}$$

Define markup μ_{igt} as price p_{igt} over marginal cost $\frac{\partial V_{igt}(c_{igt})}{\partial c_{igt}}$, i.e. $\mu_{igt} = \frac{p_{igt}}{\frac{\partial V_{igt}(c_{igt})}{\partial c_{igt}}}$

Then the above f.o.c. becomes:

$$1 - \sigma_g \tag{91}$$

$$+(\sigma_g - 1)s_{igt} \tag{92}$$

$$+\sigma_g\frac{1}{\mu_{igt}} \tag{93}$$

$$-(\sigma_{gt} - 1)s_{gt}\frac{1}{\mu_{igt}} = 0 \tag{94}$$

$$\tag{95}$$

A few lines of algebra show that the markup is equal to

$$\mu_{igt} = \frac{(\sigma_g - 1)s_{igt} - \sigma_g}{1 + (\sigma_g - 1)s_{igt} - \sigma_g} \tag{96}$$

B.2 The supply equation

Start from the markup definition

$$\mu_{igt} = \frac{p_{igt}}{\frac{\partial V_{igt}(c_{igt})}{\partial c_{igt}}} \tag{97}$$

So price of UPC i is (use definition of variable costs)

$$p_{igt} = \mu_{igt}(1+\delta_g) z_{igt} c_{igt}^{\delta_g} \tag{98}$$

Consider this condition for item i and j of the same product group and divide

$$\frac{p_{igt}}{p_{jgt}} = \frac{\mu_{igt}}{\mu_{jgt}} \frac{z_{igt}}{z_{jgt}} \frac{c_{igt}^{\delta_g}}{c_{jgt}^{\delta_g}} \tag{99}$$

Multiply both sides by $\left[\frac{p_{igt}}{p_{jgt}}\right]^{\delta_g}$

$$\left[\frac{p_{igt}}{p_{jgt}}\right]^{1+\delta_g} = \frac{\mu_{igt}}{\mu_{jgt}} \frac{z_{igt}}{z_{jgt}} \left[\frac{p_{igt}c_{igt}}{p_{jgt}c_{jgt}}\right]^{\delta_g} \tag{100}$$

By dividing both numerator and denominator in the last term by total sales of group g we have the equation with sales shares s_{igt} and s_{jgt}

Take logs

$$(1+\delta_g)(\ln p_{igt} - lnp_{jgt}) = \ln \mu_{igt} z_{igt} - \ln \mu_{jgt} z_{jgt} + \delta_g(\ln s_{igt} - \ln s_{jgt}) \tag{101}$$

Now take the same equation at time t-1 and take the time difference

$$(1+\delta_g)(\Delta \ln p_{igt} - \Delta \ln p_{jgt}) \tag{102}$$

$$= \Delta \ln \mu_{igt} z_{igt} - \Delta \ln \mu_{jgt} z_{jgt} + \delta_g(\Delta \ln s_{igt} - \Delta \ln s_{jgt}) \tag{103}$$

Using $\Delta^{i,t}$ as defined above as the joint time difference and across UPC difference

You can write the above as

$$(1+\delta_g)\Delta^{i,t} \ln p_{igt} = \Delta \ln \mu_{igt} z_{igt} + \delta_g \Delta \ln s_{igt} \tag{104}$$

Rearrange to get:

$$\Delta^{i,t} \ln p_{igt} = \frac{\delta_g}{1+\delta_g} \Delta^{i,t} \ln s_{igt} + \frac{1}{1+\delta_g} \Delta^{i,t} \ln \mu_{igt} z_{igt} \tag{105}$$

C The cost-of-living index

C.1 Derivation of the cost-of-living index

C.1.1 The minimization problem

The cost-of-living index when tastes changes is defined in the text as:

$$P_N(\mathbf{q_0}, \varphi_1, \varphi_2, \mathbf{p_2}, \mathbf{p_1}) = \frac{C(\mathbf{q_0}, \varphi_2, \mathbf{p_2})}{C(\mathbf{q_0}, \varphi_1, \mathbf{p_1})} \tag{106}$$

with the money metric function:

$$C(\mathbf{q}_0, \varphi, \mathbf{p}) = \min_{\mathbf{q}} \{\mathbf{p}.\mathbf{q} : U(\mathbf{q}, \varphi) = U(\mathbf{q}_0, \varphi)\} \tag{107}$$

The Lagrangian of the minimization problem in the money metric function is:

The Lagrangian is

$$L^* = \sum_{i \in I_g} p_{igt} c_{igt} - \lambda^* \left[U_t - U(\mathbf{q}_0, \varphi)\right] \tag{108}$$

First order Condition w.r.t. c_{igt} (use the chain rule)

$$p_{igt} - \lambda^* \frac{\delta U_t}{\delta U_{gt}} . \frac{\delta U_{gt}}{\delta c_{igt}} = 0 \tag{109}$$

If we define $\lambda = \frac{1}{\lambda^*}$

we can rewrite the foc identical to the consumers utility maximization problem

$$-\lambda p_{igt} + \frac{\delta U_t}{\delta U_{gt}} . \frac{\delta U_{gt}}{\delta c_{igt}} = 0 \tag{110}$$

C.1.2 The price aggregate and subutility

We first show that the f.o.c. of the consumer aggregated over items in a product groups leads to a statement between the price aggregate P_{gt} and subutility U_{gt} (both defined above).

Start with equation (110), the first order condition w.r.t c_{igt}.

$$-\lambda p_{igt} + \frac{\delta U_t}{\delta U_{gt}} . \frac{\delta U_{gt}}{\delta c_{igt}} = 0 \tag{111}$$

Divide by φ_{igt} and rearange,

$$\lambda \frac{p_{igt}}{\varphi_{igt}} = \frac{\delta U_t}{\delta U_{gt}} . \frac{\delta U_{gt}}{\delta c_{igt}} \frac{1}{\varphi_{igt}} \tag{112}$$

Do to power $1 - \sigma_g$ and aggregate over all items in group g.

$$\sum_{i\in I_g}(\lambda\frac{p_{igt}}{\varphi_{igt}})^{1-\sigma_g}=(\frac{\delta U_t}{\delta U_{gt}})^{1-\sigma_g}.\sum_{i\in I_g}(\frac{\delta U_{gt}}{\delta c_{igt}}\frac{1}{\varphi_{igt}})^{1-\sigma_g} \tag{113}$$

Do to power $\frac{1}{1-\sigma_g}$,

$$\lambda(\sum_{i\in I_g}(\frac{p_{igt}}{\varphi_{igt}})^{1-\sigma_g})^{\frac{1}{1-\sigma_g}}=(\frac{\delta U_t}{\delta U_{gt}}).(\sum_{i\in I_g}(\frac{\delta U_{gt}}{\delta c_{igt}}\frac{1}{\varphi_{igt}})^{1-\sigma_g})^{\frac{1}{1-\sigma_g}} \tag{114}$$

The second term on the lefthandside was defined in equation (66) as the exact price aggregate over items in product group g.

So we have,

$$\lambda P_{gt}=(\frac{\delta U_t}{\delta U_{gt}}).(\sum_{i\in I_g}(\frac{\delta U_{gt}}{\delta c_{igt}}\frac{1}{\varphi_{igt}})^{1-\sigma_g})^{\frac{1}{1-\sigma_g}} \tag{115}$$

Now we show that $(\sum_{i\in I_g}(\frac{\delta U_{gt}}{\delta c_{igt}}\frac{1}{\varphi_{igt}})^{1-\sigma_g})^{\frac{1}{1-\sigma_g}}$ is equal to 1.

Use $\frac{\delta U_{gt}}{\delta c_{igt}}$ as above in (48). We have

$$(\sum_{i\in I_g}(\frac{\delta U_{gt}}{\delta c_{igt}}\frac{1}{\varphi_{igt}})^{1-\sigma_g})^{\frac{1}{1-\sigma_g}}= \tag{116}$$

$$\Big[\sum_{i\in I_g}\Big[\varphi_{igt}\Big[\sum_{i\in I_g}(\varphi_{igt}c_{igt})^{\frac{\sigma_g-1}{\sigma_g}}\Big]^{\frac{1}{\sigma_g-1}}(\varphi_{igt}c_{igt})^{\frac{-1}{\sigma_g}}.\frac{1}{\varphi_{igt}}\Big]^{1-\sigma_g}\Big]^{\frac{1}{1-\sigma_g}} \tag{117}$$

Simplify

$$(\sum_{i\in I_g}(\frac{\delta U_{gt}}{\delta c_{igt}}\frac{1}{\varphi_{igt}})^{1-\sigma_g})^{\frac{1}{1-\sigma_g}}= \tag{118}$$

$$\Big[\sum_{i\in I_g}\Big[\Big[\sum_{i\in I_g}(\varphi_{igt}c_{igt})^{\frac{\sigma_g-1}{\sigma_g}}\Big]^{\frac{1}{\sigma_g-1}}(\varphi_{igt}c_{igt})^{\frac{-1}{\sigma_g}}\Big]^{1-\sigma_g}\Big]^{\frac{1}{1-\sigma_g}} \tag{119}$$

Simplify further,

$$(\sum_{i\in I_g}(\frac{\delta U_{gt}}{\delta c_{igt}}\frac{1}{\varphi_{igt}})^{1-\sigma_g})^{\frac{1}{1-\sigma_g}}= \tag{120}$$

$$\Big[\sum_{i\in I_g}\Big[\Big[\sum_{i\in I_g}(\varphi_{igt}c_{igt})^{\frac{\sigma_g-1}{\sigma_g}}\Big]^{-1}(\varphi_{igt}c_{igt})^{\frac{\sigma_g-1}{\sigma_g}}\Big]\Big]^{\frac{1}{1-\sigma_g}} \tag{121}$$

Which is equal to 1.

So we have shown that,

$$\lambda P_{gt}=\frac{\delta U_t}{\delta U_{gt}} \tag{122}$$

C.1.3 Total expenditure on product group g, price aggregate and utility

Now we show that total expenditure on product group g, $\sum_{i \in I_g} p_{igt} c_{igt}$ is equal to $P_{gt} U_{gt}$.

We use what we have just shown above $\lambda P_{gt} = \frac{\delta U_t}{\delta U_{gt}}$ and plug it into the foc $-\lambda p_{igt} + \frac{\delta U_t}{\delta U_{gt}} . \frac{\delta U_{gt}}{\delta c_{igt}} = 0$, we get

$$-\lambda p_{igt} + \lambda P_{gt} . \frac{\delta U_{gt}}{\delta c_{igt}} = 0 \tag{123}$$

Divide by λ,multiply by c_{igt}, sum over all i in g and rearange,

$$\sum_{i \in I_g} p_{igt} c_{igt} = P_{gt} . \sum_{i \in I_g} c_{igt} \frac{\delta U_{gt}}{\delta c_{igt}} \tag{124}$$

Again use (48),

$$\sum_{i \in I_g} p_{igt} c_{igt} = P_{gt} . \sum_{i \in I_g} \Big[\varphi_{igt} c_{igt} \Big[\sum_{i \in I_g} (\varphi_{igt} c_{igt})^{\frac{\sigma_g - 1}{\sigma_g}} \Big]^{\frac{1}{\sigma_g - 1}} (\varphi_{igt} c_{igt})^{\frac{-1}{\sigma_g}} \Big] \tag{125}$$

Simplify,

$$\sum_{i \in I_g} p_{igt} c_{igt} = P_{gt} . \sum_{i \in I_g} \Big[\Big[\sum_{i \in I_g} (\varphi_{igt} c_{igt})^{\frac{\sigma_g - 1}{\sigma_g}} \Big]^{\frac{1}{\sigma_g - 1}} (\varphi_{igt} c_{igt})^{\frac{\sigma_g - 1}{\sigma_g}} \Big] \tag{126}$$

Simplify again, (bring sum out of the outer sum)

$$\sum_{i \in I_g} p_{igt} c_{igt} = P_{gt} . \Big[\sum_{i \in I_g} (\varphi_{igt} c_{igt})^{\frac{\sigma_g - 1}{\sigma_g}} \Big]^{\frac{1}{\sigma_g - 1}} \sum_{i \in I_g} \Big[(\varphi_{igt} c_{igt})^{\frac{\sigma_g - 1}{\sigma_g}} \Big] \tag{127}$$

Using the definition of U_{gt}

$$\sum_{i \in I_g} p_{igt} c_{igt} = P_{gt} . U_{gt}^{\frac{1}{\sigma_g}} . U_{gt}^{\frac{\sigma_g - 1}{\sigma_g}} \tag{128}$$

or

$$\sum_{i \in I_g} p_{igt} c_{igt} = P_{gt} . U_{gt} \tag{129}$$

C.1.4 Total utility and total expenditure and the Lagrange multiplier

Now we will show that λ is equal to utility divided by total expenditures , $\lambda = U_t / E_t$.

Start from what we have shown above, $\sum_{i \in I_g} p_{igt} c_{igt} = P_{gt} . U_{gt}$ and also that $\lambda P_{gt} = \frac{\delta U_t}{\delta U_{gt}}$ and combine it with (46) i.e. $\frac{\delta U_t}{\delta U_{gt}} = \alpha_g \frac{U_t}{U_{gt}}$

Combining we have

$$\lambda \sum_{i \in I_g} p_{igt} c_{igt} = \frac{\delta U_t}{\delta U_{gt}} U_{gt} \tag{130}$$

$$\lambda \sum_{i \in I_g} p_{igt} c_{igt} = \alpha_g \frac{U_t}{U_{gt}} U_{gt} \tag{131}$$

$$\lambda \sum_{i \in I_g} p_{igt} c_{igt} = \alpha_g U_t \tag{132}$$

Sum over all groups g, (note $\sum_{g \in G} \alpha_g = 1$)

$$\lambda \sum_{g \in G} \sum_{i \in I_g} p_{igt} c_{igt} = U_t \tag{133}$$

or

$$\lambda E_t = U_t \tag{134}$$

C.1.5 The cost-of-living index

Now we derive the cost-of-living index, Start from

$$\lambda = \frac{U_t}{E_t} \tag{135}$$

Plug in $\lambda P_{gt} = \frac{\delta U_t}{\delta U_{gt}}$ and use $\frac{\delta U_t}{\delta U_{gt}} = \alpha_g \frac{U_t}{U_{gt}}$

$$\lambda P_{gt} = P_{gt} \frac{U_t}{E_t} \tag{136}$$

$$\frac{\delta U_t}{\delta U_{gt}} = P_{gt} \frac{U_t}{E_t} \tag{137}$$

$$\alpha_g \frac{U_t}{U_{gt}} = P_{gt} \frac{U_t}{E_t} \tag{138}$$

$$P_{gt} = \frac{E_t}{U_t} . \alpha_g \frac{U_t}{U_{gt}} \tag{139}$$

$$P_{gt} U_{gt} = \alpha_g E_t \tag{140}$$

$$U_{gt} = \frac{\alpha_g E_t}{P_{gt}} \tag{141}$$

Do power α_g and multiply over all groups g

$$\prod_{g \in G} (U_{gt})^{\alpha_g} = \prod_{g \in G} (\frac{\alpha_g E_t}{P_{gt}})^{\alpha_g} \tag{142}$$

or

$$U_t = E_t \prod_{g \in G} (\frac{\alpha_g}{P_{gt}})^{\alpha_g} \tag{143}$$

or

$$E_t = U_t \prod_{g \in G} (\frac{P_{gt}}{\alpha_g})^{\alpha_g} \tag{144}$$

We define $P_t(\varphi_t) \equiv P(\mathbf{p_t}, \boldsymbol{\varphi_t}) \equiv \prod_{g \in G} (\frac{P_{gt}}{\alpha_g})^{\alpha_g}$, we can write,

$$E_t = U(\mathbf{q}_t, \varphi_t) P(\mathbf{p_t}, \varphi_t) \tag{145}$$

Note that we write $U(\mathbf{q}_t, \varphi_t)$ and $P(\mathbf{p_t}, \varphi_t)$ to denote explicitely that utility and the price aggregate at time t depend on taste parameters

Note that the optimal consumption basket $\mathbf{q_t}$ was derived under utility maximization for a given budget E_t so that by duality E_t is also the minimum expenditure needed to obtain utility $U(\mathbf{q_t}, \varphi_t)$ at price vector $\mathbf{p}_t$, i.e. $E_t = C(\mathbf{q}_t, \varphi_t, \mathbf{p}_t)$

In other words, we have shown that for a Cobb-Douglas aggregate of CES subpreferences we have:

$$E_t = C(\mathbf{q}_t, \varphi_t, \mathbf{p}_t) = U(\mathbf{q}_t, \varphi_t) P(\mathbf{p_t}, \varphi_t) \tag{146}$$

with $\mathbf{q}_t$ the utility maximizing basket when faced with prices $\mathbf{p}_t$ and budget E_t

As defined in the main text, the cost-of-living index, in the presence of taste changes, between period t and t-1 is

$$P_N(\mathbf{q_{t-1}}, \varphi_{t-1}, \varphi_t, \mathbf{p}_t, \mathbf{p}_{t-1}) = \frac{C(\mathbf{q_{t-1}}, \varphi_t, \mathbf{p_t})}{C(\mathbf{q_{t-1}}, \varphi_{t-1}, \mathbf{p_{t-1}})} \tag{147}$$

Now the denominator denotes optimal expenditure in period t-1,

$$C(\mathbf{q_{t-1}}, \varphi_{t-1}, \mathbf{p_{t-1}}) = U(\mathbf{q_{t-1}}, \varphi_{t-1}) P(\mathbf{p_{t-1}}, \varphi_{t-1}) \tag{148}$$

The numerator measures minimum expenditure needed to reach the utility curve that goes through the base period basket under the period t prices, i.e. ,

$$C(\mathbf{q_{t-1}}, \varphi_t, \mathbf{p_t}) = U(\mathbf{q_{t-1}}, \varphi_t) P(\mathbf{p_t}, \varphi_t) \tag{149}$$

where $U(\mathbf{q}_{t-1}, \varphi_t)$ denotes the utility of consuming the basket $\mathbf{q}_{t-1}$ under the period t taste parameters.

So that we have

$$P_N = \frac{U(\mathbf{q_{t-1}}, \varphi_t)}{U(\mathbf{q_{t-1}}, \varphi_{t-1})} \frac{P(\mathbf{p_t}, \varphi_t)}{P(\mathbf{p_{t-1}}, \varphi_{t-1})} \tag{150}$$

or

$$P_N = \frac{U(\mathbf{q_{t-1}}, \varphi_t)}{U(\mathbf{q_{t-1}}, \varphi_{t-1})} \prod_{g \in G} [\frac{P_g(\mathbf{p_{gt}}, \varphi_{gt})}{P_g(\mathbf{p_{gt-1}}, \varphi_{gt-1})}]^{\alpha_g} \tag{151}$$

C.2 Separating the price effect from the taste change effect

The cost of living index under changing preferences can also be written as,

$$P_N = \frac{C(\mathbf{q_{t-1}}, \varphi_t, \mathbf{p_t})}{C(\mathbf{q_{t-1}}, \varphi_t, \mathbf{p_{t-1}})} \frac{C(\mathbf{q_{t-1}}, \varphi_t, \mathbf{p_{t-1}})}{C(\mathbf{q_{t-1}}, \varphi_{t-1}, \mathbf{p_{t-1}})} \tag{152}$$

where $\frac{C(\mathbf{q_{t-1}}, \varphi_t, \mathbf{p_t})}{C(\mathbf{q_{t-1}}, \varphi_t, \mathbf{p_{t-1}})}$ measures the price effect and $\frac{C(\mathbf{q_{t-1}}, \varphi_t, \mathbf{p_{t-1}})}{C(\mathbf{q_{t-1}}, \varphi_{t-1}, \mathbf{p_{t-1}})}$ measures the taste change effect.

Note that the denominator of the price effect is the minimum expenditure needed to obtain utility in period t at the base period basket at prices of t-1, which is,

$$C(\mathbf{q_{t-1}}, \varphi_t, \mathbf{p_{t-1}}) = U(\mathbf{q_{t-1}}, \varphi_t) P(\mathbf{p_{t-1}}, \varphi_t) \tag{153}$$

Importantly,$P(\mathbf{p_{t-1}}, \varphi_t)$ denotes the price aggregate at prices of period t-1 constructed using taste parameters of period t!

So the cost of living index using our CES preferences becomes,

$$P_N = \frac{U(\mathbf{q_{t-1}}, \varphi_t) P(\mathbf{p_t}, \varphi_t)}{U(\mathbf{q_{t-1}}, \varphi_t) P(\mathbf{p_{t-1}}, \varphi_t)} * \frac{U(q_{t-1}, \varphi_t) P(\mathbf{p_{t-1}}, \varphi_t)}{U(q_{t-1}, \varphi_{t-1}) P(\mathbf{p_{t-1}}, \varphi_{t-1})} \tag{154}$$

Which is equal to

$$P_N = \frac{P(\mathbf{p_t}, \varphi_t)}{P(\mathbf{p_{t-1}}, \varphi_t)} * \frac{U(q_{t-1}, \varphi_t) P(\mathbf{p_{t-1}}, \varphi_t)}{U(q_{t-1}, \varphi_{t-1}) P(\mathbf{p_{t-1}}, \varphi_{t-1})} \tag{155}$$

where the first term gives the price-effect : $\frac{P(\mathbf{p_t}, \varphi_t)}{P(\mathbf{p_{t-1}}, \varphi_t)}$ and the second term gives the taste-effect: $\frac{U(q_{t-1}, \varphi_t) P(\mathbf{p_{t-1}}, \varphi_t)}{U(q_{t-1}, \varphi_{t-1}) P(\mathbf{p_{t-1}}, \varphi_{t-1})}$.

C.3 Writing $\frac{P_g(\mathbf{p_{gt}}, \varphi_{gt})}{P_g(\mathbf{p_{gt-1}}, \varphi_{gt-1})}$ as a Sato-Vartia index

In this section we show that $\frac{P_g(\mathbf{p_{gt}}, \varphi_{gt})}{P_g(\mathbf{p_{gt-1}}, \varphi_{gt-1})}$ can be written as a weighted geometric average of price ratio's and taste parameter ratio's.

We start with the equation (71) given above,

$$s_{igt} = \frac{(\frac{p_{igt}}{\varphi_{igt}})^{1-\sigma_g}}{P_{gt}^{1-\sigma_g}} \tag{156}$$

or

$$\varphi_{igt}^{1-\sigma_g} . s_{igt} = \frac{(p_{igt})^{1-\sigma_g}}{P_{gt}^{1-\sigma_g}} \tag{157}$$

or

$$\varphi_{igt} = s_{igt}^{\frac{-1}{1-\sigma_g}} \frac{p_{igt}}{P_{gt}} \tag{158}$$

or

$$P_{gt} = s_{igt}^{\frac{-1}{1-\sigma_g}} p_{igt}.\varphi_{igt}^{-1} \tag{159}$$

Divide by the same equation at t-1.

$$\frac{P_{gt}}{P_{gt-1}} = (\frac{s_{igt}}{s_{igt-1}})^{\frac{-1}{1-\sigma_g}} \frac{p_{igt}}{p_{igt-1}}.\frac{\varphi_{igt-1}}{\varphi_{igt}} \tag{160}$$

Take logs

$$\ln\frac{P_{gt}}{P_{gt-1}} = \ln(\frac{p_{igt}}{p_{igt-1}}.\frac{\varphi_{igt-1}}{\varphi_{igt}}) - \frac{1}{(1-\sigma_g)}\ln(\frac{s_{igt}}{s_{igt-1}}) \tag{161}$$

Define log-change weights,

$$w_{igt} = \frac{f(s_{igt}, s_{igt-1})}{\sum_{i\in I_g} f(s_{igt}, s_{igt-1})} \tag{162}$$

using the log-change function f,

$$f(y,x) = \frac{y-x}{\ln y - \ln x} \tag{163}$$

and for $y = x$ f is defined as,

$$f(x,x) = x \tag{164}$$

Note that w_{igt} summed over all i in g is equal to 1. Multiply both sides of equation (161) by the weights w_{igt}

$$w_{igt}\ln\frac{P_{gt}}{P_{gt-1}} = w_{igt}\ln(\frac{p_{igt}}{p_{igt-1}}.\frac{\varphi_{igt-1}}{\varphi_{igt}}) - \frac{1}{(1-\sigma_g)}w_{igt}\ln(\frac{s_{igt}}{s_{igt-1}}) \tag{165}$$

Use definition of log-change weight,

$$w_{igt}\ln\frac{P_{gt}}{P_{gt-1}} = w_{igt}\ln(\frac{p_{igt}}{p_{igt-1}}.\frac{\varphi_{igt-1}}{\varphi_{igt}}) - \frac{1}{(1-\sigma_g)}\frac{f(s_{igt}, s_{igt-1})}{\sum_{i\in I_g} f(s_{igt}, s_{igt-1})}\ln(\frac{s_{igt}}{s_{igt-1}}) \tag{166}$$

In case $s_{igt} = s_{igt-1}$ the last term is zero, in case the shares are different the last term becomes,

$$\frac{s_{igt} - s_{igt-1}}{\sum_{i\in I_g} f(s_{igt}, s_{igt-1})} \tag{167}$$

When summed over all i in g, this is zero (as shares in each period sum up to 1).

So summing equation (166) over all i in product groug , we get

$$\ln\frac{P_{gt}}{P_{gt-1}} = \sum_{i\in I_g} w_{igt}\ln(\frac{p_{igt}}{p_{igt-1}}.\frac{\varphi_{igt-1}}{\varphi_{igt}}) \tag{168}$$

or

$$\frac{P_{gt}}{P_{gt-1}} = \prod_{i \in I_g} (\frac{p_{igt}}{p_{igt-1}} . \frac{\varphi_{igt-1}}{\varphi_{igt}})^{w_{igt}} \tag{169}$$

which is the Sato-Vartia index (corrected for taste shocks).

C.4 Writing $\frac{P_g(\mathbf{p_{gt}},\varphi_{gt})}{P_g(\mathbf{p_{gt-1}},\varphi_{gt-1})}$ as a common-goods price index

In this section, we show how $\frac{P_g(\mathbf{p_{gt}},\varphi_{gt})}{P_g(\mathbf{p_{gt-1}},\varphi_{gt-1})}$ can be written as a common-goods price index as in Redding and Weinstein (2016) (which is identical to their unified price index in the absence of changes in the number of varieties).

Start from equation (160):

$$\frac{P_{gt}}{P_{gt-1}} = (\frac{s_{igt}}{s_{igt-1}})^{\frac{-1}{1-\sigma_g}} \frac{p_{igt}}{p_{igt-1}} . \frac{\varphi_{igt-1}}{\varphi_{igt}} \tag{170}$$

Take logs and sum over all i $\in I_g$.

$$\sum_{i \in I_g} \ln \frac{P_{gt}}{P_{gt-1}} = \sum_{i \in I_g} \ln \frac{p_{igt}}{p_{igt-1}} + \sum_{i \in I_g} \ln \frac{\varphi_{igt-1}}{\varphi_{igt}} - \frac{1}{1-\sigma_g} \sum_{i \in I_g} \ln(\frac{s_{igt}}{s_{igt-1}}) \tag{171}$$

Note that we have assumed that $\prod \varphi_{igt} = 1$ and $\prod \varphi_{igt-1} = 1$. So we have that $\sum_{i \in I_g} \ln \frac{\varphi_{igt-1}}{\varphi_{igt}} = 0$. So we have: ($N_g$ is the number of product varieties)

$$N_g \ln \frac{P_{gt}}{P_{gt-1}} = \sum_{i \in I_g} \ln \frac{p_{igt}}{p_{igt-1}} - \frac{1}{1-\sigma_g} \sum_{i \in I_g} \ln(\frac{s_{igt}}{s_{igt-1}}) \tag{172}$$

Divide by N_g on both sides:

$$\ln \frac{P_{gt}}{P_{gt-1}} = \sum_{i \in I_g} \ln(\frac{p_{igt}}{p_{igt-1}})^{1/N_g} - \frac{1}{1-\sigma_g} \sum_{i \in I_g} \ln(\frac{s_{igt}}{s_{igt-1}})^{1/N_g} \tag{173}$$

or

$$\frac{P_{gt}}{P_{gt-1}} = \prod_{i \in I_g} (\frac{p_{igt}}{p_{igt-1}})^{1/N_g} (\frac{s_{igt}}{s_{igt-1}})^{(1/N_g)(1/(\sigma_g-1))} \tag{174}$$

Note that Redding and Weinstein (2016) define the common-goods price index or unified price index to be a cost-of-living index. They state '*Our objective in this paper is to allow for demand shifts for individual goods while still being able to make consistent comparisons of welfare over time. To be able to make such consistent welfare comparisons between a pair of time periods, one must obtain the same change in the cost of living whether one uses today's preferences for both periods, yesterday's preferences for both periods, of the preferences of each period (so that all three comparisons are consistent with one another)*. For this to be true they require *'demand-shocks that do not directly affect utility'*. So they start by expressing the change in the cost-of-living as the ratio between the unit expenditure functions in both periods $\frac{P_{gt}}{P_{gt-1}}$ (see their equation (4)). However the 'units' of expenditure are not comparable if tastes change. Following our theoretical definition of cost-of-living (which follows Bassmann et al. (1984) and Balk (1989) this ratio is not equal to a cost-of-living. It needs to be pre-multiplied by the ratio of utilities in both periods.

C.5 A formula for taste shocks as a function of prices, expenditures shares and the elasticity of substitution

Start with equation (71) above

$$s_{igt} = \frac{(\frac{p_{igt}}{\varphi_{igt}})^{1-\sigma_g}}{\sum_{j\in I_g}(\frac{p_{jgt}}{\varphi_{jgt}})^{1-\sigma_g}} \tag{175}$$

Let there be N_g varieties (i.e. the number of elements i in I_g). Do above equation to power $1/N_g$.

$$s_{igt}^{1/N_g} = \frac{(\frac{p_{igt}}{\varphi_{igt}})^{\frac{1-\sigma_g}{N_g}}}{\left[\sum_{j\in I_g}(\frac{p_{jgt}}{\varphi_{jgt}})^{1-\sigma_g}\right]^{\frac{1}{N_g}}} \tag{176}$$

You have one such equation for every i in I_g.

Multiply these N_g equations.

$$\prod_{i\in I_g} s_{igt}^{1/N_g} = \frac{\prod_{i\in I_g}(\frac{p_{igt}}{\varphi_{igt}})^{\frac{1-\sigma_g}{N_g}}}{\sum_{j\in I_g}(\frac{p_{jgt}}{\varphi_{jgt}})^{1-\sigma_g}} \tag{177}$$

Or

$$\prod_{i\in I_g} s_{igt}^{1/N_g} = \frac{\left[\prod(\frac{p_{igt}}{\varphi_{igt}})^{\frac{1}{N_g}}\right]^{1-\sigma_g}}{\sum_{j\in I}(\frac{p_{jt}}{\varphi_{jt}})^{1-\sigma}} \tag{178}$$

Or

$$\prod_{i\in I_g} s_{igt}^{1/N_g} = \frac{\left[(\frac{\prod p_{igt}^{\frac{1}{N_g}}}{\prod \varphi_{igt}^{\frac{1}{N_g}}})\right]^{1-\sigma_g}}{\sum_{j\in I_g}(\frac{p_{jgt}}{\varphi_{jgt}})^{1-\sigma_g}} \tag{179}$$

Now divide the share equation above by this equation, you get:

$$\frac{s_{igt}}{\prod s_{igt}^{1/N_g}} = \frac{(\frac{p_{igt}}{\varphi_{igt}})^{1-\sigma_g}}{\left[(\frac{\prod p_{igt}^{\frac{1}{N_g}}}{\prod \varphi_{igt}^{\frac{1}{N_g}}})\right]^{1-\sigma_g}} \tag{180}$$

Do power $\frac{1}{1-\sigma_g}$

$$\frac{s_{igt}}{\prod s_{igt}^{1/N_g}}^{\frac{1}{1-\sigma_g}} = \frac{(\frac{p_{igt}}{\varphi_{igt}})}{(\prod p_{igt}^{\frac{1}{N_g}})} . \prod \varphi_{igt}^{\frac{1}{N_g}} \tag{181}$$

Or

$$\varphi_{igt} = \Big[\frac{p_{igt}}{\prod p_{igt}^{(1/N_g)}} / \Big[\frac{s_{igt}}{\prod s_{igt}^{1/N_g}}\Big]^{\frac{1}{1-\sigma_g}}\Big] . \prod \varphi_{igt}^{\frac{1}{N_g}} \tag{182}$$

Note that the normalisation of taste parameters implies that taste shocks, on average cancel out (i.e. $\prod_{i \in I_g} (\frac{\varphi_{igt-1}}{\varphi_{igt}})^{\frac{1}{N_g}} = 1$) we have that taste parameters are equal to,

$$\varphi_{igt} = \Big[\frac{p_{igt}}{\prod p_{igt}^{(1/N_g)}} / \Big[\frac{s_{igt}}{\prod s_{igt}^{1/N_g}}\Big]^{\frac{1}{1-\sigma_g}}\Big]. \tag{183}$$

and ratios of taste parameters in period t and t-1 are equal to

$$\varphi_{igt-1}/\varphi_{igt} = \Big[\frac{p_{igt-1}}{\prod p_{igt-1}^{(1/N)}} / \Big[\frac{s_{igt-1}}{\prod s_{it-1}^{1/N}}\Big]^{\frac{1}{1-\sigma_g}}\Big] / \Big[\frac{p_{igt}}{\prod p_{igt}^{(1/N)}} / \Big[\frac{s_{igt}}{\prod s_{it}^{1/N}}\Big]^{\frac{1}{1-\sigma_g}}\Big] \tag{184}$$

D Example of the cost-of-living index

In this section we give an example of the cost-of-living index for the simplest case of two goods.

Utility at time t is,

$$U_t = \Big[(\varphi_{1t} c_{1t})^{\frac{\sigma-1}{\sigma}} + (\varphi_{2t} c_{2t})^{\frac{\sigma-1}{\sigma}}\Big]^{\frac{\sigma}{\sigma-1}} \tag{185}$$

The exact price index at time t is,

$$P_t = \Big[(\frac{p_{1t}}{\varphi_{1t}})^{1-\sigma} + (\frac{p_{2t}}{\varphi_{2t}})^{1-\sigma}\Big]^{\frac{1}{1-\sigma}} \tag{186}$$

And consumer optimization at $U_t = U*$ guarantees that the following holds for every $U*$,

$$E_t = U_t . P_t \tag{187}$$

The cost-of-living index defined in the main text is now,

$$COLIT = \frac{C(U(\mathbf{q_{t-1}}, \varphi_t), \mathbf{p_t})}{C(U(\mathbf{q_{t-1}}, \varphi_t), \mathbf{p_{t-1}})} \frac{C(U(\mathbf{q_{t-1}}, \varphi_t), \mathbf{p_{t-1}})}{C(U(\mathbf{q_{t-1}}, \varphi_{t-1}), \mathbf{p_{t-1}})} \tag{188}$$

Whose elements are:

$$C(U(\mathbf{q_{t-1}}, \varphi_t), \mathbf{p_t}) = U_t^*(q_{t-1}).P_t = \tag{189}$$

$$\Big[(\varphi_{1t} c_{1t-1})^{\frac{\sigma-1}{\sigma}} + (\varphi_{2t} c_{2t-1})^{\frac{\sigma-1}{\sigma}}\Big]^{\frac{\sigma}{\sigma-1}} . \Big[(\frac{p_{1t}}{\varphi_{1t}})^{1-\sigma} + (\frac{p_{2t}}{\varphi_{2t}})^{1-\sigma}\Big]^{\frac{1}{1-\sigma}} \tag{190}$$

$$C(U(\mathbf{q_{t-1}},\varphi_t),\mathbf{p_{t-1}}) = U_t^*(q_{t-1}).P_{t-1}^* = \tag{191}$$

$$\left[(\varphi_{1t}c_{1t-1})^{\frac{\sigma-1}{\sigma}} + (\varphi_{2t}c_{2t-1})^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}\left[(\frac{p_{1t-1}}{\varphi_{1t}})^{1-\sigma} + (\frac{p_{2t-1}}{\varphi_{2t}})^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{192}$$

Note that P_{t-1}^* has prices at time t-1 with φ's at time t.

$$C(U(\mathbf{q_{t-1}},\varphi_{t-1}),\mathbf{p_{t-1}}) = U_{t-1}(q_{t-1}).P_{t-1} = \tag{193}$$

$$\left[(\varphi_{1t-1}c_{1t-1})^{\frac{\sigma-1}{\sigma}} + (\varphi_{2t-1}c_{2t-1})^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}\left[(\frac{p_{1t-1}}{\varphi_{1t-1}})^{1-\sigma} + (\frac{p_{2t-1}}{\varphi_{2t-1}})^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{194}$$

So that the COLIT can be separated into its pure price effect and its taste change effect

$$PRICE-EFFECT = \frac{C(U(\mathbf{q_{t-1}},\varphi_t),\mathbf{p_t})}{C(U(\mathbf{q_{t-1}},\varphi_t),\mathbf{p_{t-1}})} = \frac{\left[(\frac{p_{1t}}{\varphi_{1t}})^{1-\sigma} + (\frac{p_{2t}}{\varphi_{2t}})^{1-\sigma}\right]^{\frac{1}{1-\sigma}}}{\left[(\frac{p_{1t-1}}{\varphi_{1t}})^{1-\sigma} + (\frac{p_{2t-1}}{\varphi_{2t}})^{1-\sigma}\right]^{\frac{1}{1-\sigma}}} \tag{195}$$

Note that the price-effect measure the effect of a pure price change using constant taste (at time t)

$$TASTE-EFFECT = \frac{C(U(\mathbf{q_{t-1}},\varphi_t),\mathbf{p_{t-1}})}{C(U(\mathbf{q_{t-1}},\varphi_{t-1}),\mathbf{p_{t-1}})} = \tag{196}$$

$$\frac{\left[(\varphi_{1t}c_{1t-1})^{\frac{\sigma-1}{\sigma}} + (\varphi_{2t}c_{2t-1})^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}}{\left[(\varphi_{1t-1}c_{1t-1})^{\frac{\sigma-1}{\sigma}} + (\varphi_{2t-1}c_{2t-1})^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}}\frac{\left[(\frac{p_{1t-1}}{\varphi_{1t}})^{1-\sigma} + (\frac{p_{2t-1}}{\varphi_{2t}})^{1-\sigma}\right]^{\frac{1}{1-\sigma}}}{\left[(\frac{p_{1t-1}}{\varphi_{1t-1}})^{1-\sigma} + (\frac{p_{2t-1}}{\varphi_{2t-1}})^{1-\sigma}\right]^{\frac{1}{1-\sigma}}} \tag{197}$$

The taste change effect consists of two parts, the taste change has an effect on the utility of the fixed basket of t-1 and has an effect on the weights of the price index.

D.1 Prices index and quantity index

In this section we show how the expenditure change between two periods can be written as the product of a price index and a quantity index. Consider period 1 and 2 with nominal expenditures E_1 and E_2. We will derive $\mathbf{P}$ and $\mathbf{Q}$. So that:

$$\frac{E_2}{E_1} = \frac{\mathbf{P}_2}{\mathbf{P}_1}\frac{\mathbf{Q}_2}{\mathbf{Q}_1} \tag{198}$$

consumer optimization implies that:

$$\frac{E_2}{E_1} == \frac{C(\mathbf{q_2},\varphi_2,\mathbf{p_2})}{C(\mathbf{q_1},\varphi_1,\mathbf{p_1})} \tag{199}$$

where $\mathbf{q_2}$ and $\mathbf{q_1}$ are the optimizing baskets.

Then,

$$\frac{E_2}{E_1} == \frac{C(\mathbf{q_2}, \varphi_2, \mathbf{p_2})}{C(\mathbf{q_1}, \varphi_1, \mathbf{p_1})} \frac{C(\mathbf{q_1}, \varphi_2, \mathbf{p_2})}{C(\mathbf{q_1}, \varphi_2, \mathbf{p_2})} \tag{200}$$

Rearange :

$$\frac{E_2}{E_1} == \frac{C(\mathbf{q_1}, \varphi_2, \mathbf{p_2})}{C(\mathbf{q_1}, \varphi_1, \mathbf{p_1})} \frac{C(\mathbf{q_2}, \varphi_2, \mathbf{p_2})}{C(\mathbf{q_1}, \varphi_2, \mathbf{p_2})} \tag{201}$$

The first term is our price index under taste changes.

$$P_N = \frac{C(\mathbf{q_1}, \varphi_2, \mathbf{p_2})}{C(\mathbf{q_1}, \varphi_1, \mathbf{p_1})} \tag{202}$$

The second term is the quantity index.

$$Q_N = \frac{C(\mathbf{q_2}, \varphi_2, \mathbf{p_2})}{C(\mathbf{q_1}, \varphi_2, \mathbf{p_2})} \tag{203}$$

The price index can again be written as a combination of a pure price effect and a taste effect. THe quantity index can be written as a pure utility effect.

We use:

$$C(\mathbf{q_1}, \varphi_1, \mathbf{p_1}) = U(\mathbf{q_1}, \varphi_1) P(\mathbf{p_1}, \varphi_1) \tag{204}$$

and

$$C(\mathbf{q_2}, \varphi_2, \mathbf{p_2}) = U(\mathbf{q_2}, \varphi_2) P(\mathbf{p_2}, \varphi_2) \tag{205}$$

and

$$C(\mathbf{q_1}, \varphi_2, \mathbf{p_2}) = U(\mathbf{q_1}, \varphi_2) P(\mathbf{p_2}, \varphi_2) \tag{206}$$

Then the price index under taste changes becomes (as shown already above)

$$P_N = \frac{P(\mathbf{p_2}, \varphi_2)}{P(\mathbf{p_1}, \varphi_2)} * \frac{U(q_1, \varphi_2) P(\mathbf{p_1}, \varphi_2)}{U(q_1, \varphi_1) P(\mathbf{p_1}, \varphi_1)} \tag{207}$$

with the first term the price effect and the second term the taste effect

Then the quantity index becomes:

$$Q_N = \frac{U(q_2, \varphi_2)}{U(q_1, \varphi_2)} \tag{208}$$

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