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A Composite Inter-Temporal Economic Insecurity Index

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Abstract
Interest in the study of economic insecurity has grown in recent years. However, the ongoing debate about how to measure it remains unresolved. On the assumption that economic insecurity is related both to the forward-looking perception of future outcomes based on past experience and to the perception of one's own situation compared to others in the present, we propose a class of objective individual composite inter-temporal indices of economic insecurity. The indices are obtained by combining two components, one longitudinal and one cross-sectional. In order to combine the two components, we propose a novel method that takes advantage of the availability of subjective self-assessments of one's own economic conditions. The composite inter-temporal index is applied to the European Union-Statistics on Income and Living Conditions (EU-SILC) Longitudinal Dataset, encompassing a selection of European countries. Our analysis shows that the proposed class provides new insights into individual perceptions of well-being that are not captured by poverty and inequality measures. It also provides individual measures that can be used to study the relationship between economic insecurity and other phenomena.

Keywords Composite indices · Economic insecurity · EU-SILC data · Relative indices

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1 Introduction

Economic insecurity has received increasing attention in the literature in recent decades. This phenomenon is usually associated with individuals' feelings of anxiety and worry about their future economic conditions and their possible future difficulties in overcoming economic adversity. These feelings may be generated by current economic precariousness and/or past experiences, such as difficulties already experienced in recovering from adverse economic events. In this regard, the global crisis of 2008 led to situations of uncertainty in the economic and financial systems, with devastating social consequences. The successive recovery was particularly slow in Europe compared to the US, albeit with a certain variability between European countries.

The consequent widespread sense of insecurity has been linked to many other phenomena and human behaviors. It turns out to be related with, for example, fertility intentions (Modena et al., 2014; Clark & Lepinteur, 2022), marriage intentions (Clark et al., 2023), weight gains (Smith et al., 2009; Watson, 2018; Watson et al., 2020) and mental health (Rohde et al., 2016; Watson & Osberg, 2017). For these reasons, many efforts have been made in the literature to precisely define and measure it.

Several precise definitions of economic insecurity and corresponding measures have been proposed (Osberg, 1998; Stiglitz et al., 2009; Bossert & D'Ambrosio, 2013; among others). Nevertheless, a generally accepted definition and measurement have not yet been established.

In this paper, we adhere to the idea of defining economic insecurity based on the individual's forward-looking perception of future outcomes based on past experience, as a conspicuous strand of literature (Bossert & D'Ambrosio, 2013; Hacker et al., 2014; Bossert et al., 2022; Gallo et al., 2022). In particular, we refer to the recent definition of economic insecurity provided by Bossert and D'Ambrosio (2013): "the anxiety produced by the possible exposure to adverse economic events and by the anticipation of the difficulty to recover from them". Nevertheless, we also believe that the level of economic insecurity perceived by an individual cannot exclude a further dimension of insecurity, represented by the comparison with the surrounding environment, i.e. with the people who are close to us and whom we consider to be our peers. Not only our experience, but also where we are in the distribution of the resources influences our perception. Therefore, we think it is necessary to propose a new definition of economic insecurity that, for the first time, acknowledges the existence of "two terms of comparison": *i*) each individual's own past, and *ii*) each individual's peers at the present time. The definition we propose expands that of Bossert and D'Ambrosio (2013) as "the anxiety produced by the possible exposure to adverse economic events and by the anticipation of the difficulty of recovering from them, combined with the anxiety associated with views of one's own economic condition that are unfavorable compared to others". In line with this definition, we accordingly develop a class of "composite inter-temporal indices" of economic insecurity that includes two components: a longitudinal component and a cross-sectional component. The longitudinal component takes into account the individuals' resource fluctuations over time and their ability to recover. The cross-sectional component represents the perception of one's own condition compared to others at the current time. We call this new approach "composite inter-temporal economic insecurity".

The idea of embedding the comparison of an individual with an appropriate reference group represents the novelty of this paper, as it is new in studies of economic insecurity.

However, the comparison of an individual with an appropriate reference group has been widely considered in the literature on well-being, as will be discussed in Sect. 2.

Moreover, to the best of our knowledge, the economic literature on measures of economic hardship has rarely developed composite indices that include both longitudinal and cross-sectional components. One exception is due to Ceriani and Gigliarano (2015), who focus on the measurement of "relative deprivation" and propose a class of relative indices that take into account both the relative position of individuals with respect to others and their relative position with respect to their own past.

The longitudinal component of our composite inter-temporal indices is the class of relative indices already proposed by Gallo et al. (2022). As a cross-sectional component we choose the comparison, in relative terms, with the median of the resource in the reference group, considering that the median is often used as a benchmark in the literature on poverty and relative deprivation.

To combine the two components, the longitudinal one and the cross-sectional, we consider a weighted mean, as is often done in the literature (Nardo et al., 2005; De Muro et al., 2011; Gutierrez Sanin et al., 2013). Moreover, we propose to obtain the weights for the two components based on a novel approach that exploits the availability of answers to subjective survey questions on the perception of one's economic situation. Such answers are used to derive subjective insecurity indices. The composite inter-temporal indices obtained are shown to satisfy a set of desirable properties; *Gain-loss monotonicity*; *Proximity monotonicity*; *Quasilinearity*; *Stationarity* and *Scale invariance* (a property related to relative changes).

We apply a measure of the class suggested to longitudinal data taken from the European Union-Statistics on Income and Living Conditions (EU-SILC) from 2011 to 2019, highlighting the insights we may gain from our proposal. We focus on ten European countries: Italy, France, Austria, Greece, Spain, Poland, Finland, Belgium, Denmark and Sweden. The countries are chosen to represent southern, central and northern Europe. The economic resource used is household equivalized disposable income.

The results obtained from the comparison between the two components show, in almost all countries: *i*) a high degree of heterogeneity in the combinations of values they assume and *ii*) noticeable changes on average over time. A comparison between the proposed index and other economic insecurity indices highlights some relevant differences, especially in detecting the most and least insecure individuals. Moreover, the results of a comparison with other measures of well-being highlight the ability of the proposed index to capture the resilience of some of the countries over the period considered. Finally, the proposed index is used to compare economic insecurity, on average, in different demographic and socio-economic groups. Results show a greater incidence of insecurity in some categories, such as females, over 70, unmarried, unemployed, and single-member families.

The paper is organized as follows. Section 2 briefly reviews the literature on economic insecurity. Section 3 describes the proposed composite inter-temporal indices of economic insecurity, together with the properties that the indices satisfy. Section 4 describes the data used. Section 5 discusses the results of the comparisons: between the two components of the indices, between the proposed indices and other measures of economic inequality, between the European Union countries considered and with other measures of poverty and inequality. Section 6 uses the measure to compare economic insecurity in subpopulations. Section 7 provides the concluding remarks.

2 Literature Review

There are several definitions of economic insecurity in the literature. Osberg (1998), for example, refers to economic insecurity as the "anxiety produced by a lack of economic safety", while Stiglitz et al. (2009) define it as the "uncertainty about the material conditions that may prevail in the future". More recently, Bossert and D'Ambrosio (2013) use the definition of economic insecurity as "the anxiety produced by the possible exposure to adverse economic events and by the anticipation of the difficulty to recover from them".

Following the discussion of the definition, even more ambiguity emerges about how to measure economic insecurity (Osberg, 2015; Rohde & Tang, 2018). As the literature on economic insecurity indices has expanded, several measures have been proposed that may be classified in the following ways. Firstly, they can be computed at the aggregate level, such as the International Labor Organization's (ILO) indicator (Rohde & Tang, 2018) or the Osberg and Sharpe (2014) approach. Otherwise, they can be computed at the individual level. This comes with more limitations and assumptions than in the aggregate case (Rohde & Tang, 2018), but undoubtedly offers many possibilities for analysing the relationship between economic insecurity and several individual behaviours and conditions. Secondly, they can have a retrospective (backwards-looking) approach or a prospective (forward-looking) one. In the former case, economic insecurity is measured using past data (some examples are Bossert and D'Ambrosio, 2013; Hacker et al., 2014). In the latter case, economic insecurity is measured in relation to the notion of risk (as in Cantó et al., 2020; Rohde et al., 2020). Lastly, they can be classified into subjective measures or objective measures. Subjective measures are based on responses to subjective survey questions about the perception of one's own condition and feeling of insecurity. Objective measures are based on objective data concerning an economic resource (income, wealth, etc.) or the condition in the labor market (Rohde et al., 2022).

The relationship between the subjective measures of insecurity and other phenomena has been studied by several authors. For example, Rebechi and Rohde (2023) studies the link between economic insecurity and right-wing populism, Clark et al. (2023) with marriage probability and Clark and Lepinteur (2022) with fertility. On the other hand, objective measures of economic insecurity tend to focus on backward-looking techniques capable of predicting some value of a forward-looking perception of insecurity. A certain diversity of approaches has been proposed in the literature on objective measurement. Some authors suggest identifying different dimensions of insecurity and then summarizing them using Principal Component Analysis (Rohde et al., 2015; Ranci et al., 2021). Others classify those individuals whose income flow deviates more from a given benchmark as more insecure (Rohde et al., 2014). Hacker et al. (2014) consider specific conditions that may occur in an individual's life and synthesize such conditions through a dummy variable.

Bossert and D'Ambrosio (2013) and Bossert et al. (2022) suggest a class of indices using an axiomatic approach. Their indices are calculated at the individual level and use past fluctuations in resource flows. In particular, they provide insecurity scores by taking into account absolute pairwise differences in past resource levels. These indices assign higher levels of insecurity to individuals who are unable to recover from a loss of resources.

Building on this research, Gallo et al. (2022) propose to consider the relativization of the pairwise differences included in the Bossert and D'Ambrosio (2013) measures. They justify the proposal of relative measures on several grounds, most notably the consideration that

two individuals experiencing the same loss in resources in the same period will perceive different levels of insecurity if they start from different resource levels.

The composite inter-temporal indices proposed in this paper also involve the comparison of an individual with an appropriate reference group. This implies the definition of such a group. In the literature on social identification within a reference group, seminal works by Akerlof and Kranton (2000) and Shayo (2009) present a theoretical framework for understanding the dynamics of such identification. Typically, identification is based on the conceptual distance in a given space (Nosofsky, 1992). The impact of social identification has significant implications for individual behavior (Shayo, 2020). For example, studies by Shayo (2009) and Grossman and Helpman (2018) explore the impact of individuals' social identification on their preferences regarding income redistribution. The results show that identifying with poor groups can lead to lower preferences for income redistribution than identifying with rich groups. Moreover, LeBoeuf et al. (2010) and Atkin et al. (2021) study the effect of ingroup behavior on consumer choices, finding that individuals may prefer products with features salient to their social group.

On the other hand, individual comparison with others, beyond social identification, has a prominent role in the literature on relative deprivation (Runciman, 1966; Yitzhaki, 1979; Chakravarty, 2007; Bossert et al., 2007). This literature employs the term "relative" to denote interpersonal comparisons (Ceriani & Gigliarano, 2015). Relative deprivation is the feeling experienced by individuals when they realize that they are in a less favorable position than someone else in society (Davis, 1959; Runciman, 1966).

We acknowledge that both social identification and economic comparison may have consequences on perceived economic insecurity. However, in this paper we concentrate on the comparison with a pre-identified social group, considering the process of social identification as predetermined.

Relative deprivation only refers to the negative sensation produced by the realization that others are better off. Instead, we argue that economic insecurity may also be influenced in the opposite way. Individuals may be less insecure when realizing they are in a more favorable position compared to their peers. Moreover, relative deprivation is usually considered with respect to the entire society (Yitzhaki, 1979; Bossert et al., 2012; Ceriani & Gigliarano, 2015). In our case, we assume that individuals relate themselves to a specific reference group, as is often done in the literature on well-being (see, for example, Clark & Oswald, 1996; McBride, 2001; Ferrer-i-Carbonell, 2005; D'Ambrosio et al., 2020). In this paper, the choice of the variables which identifies the reference groups relies on this strand of literature (see Sect. 4.1).

3 Composite Inter-Temporal Insecurity Indices

3.1 The Two Components

Based on the definition of economic insecurity presented in Sect. 1, we propose a class of composite inter-temporal indices that include a longitudinal component and a cross-sectional component. This section describes the two components of the indices and the method used to combine them.

As a longitudinal component we consider the class of indices proposed by Gallo et al. (2022), which are calculated at individual level by working with past resource flow fluctuations expressed in relative terms. These measures, following Bossert and D'Ambrosio (2013), assign a higher level of insecurity to individuals who are unable to recover after experiencing a loss in resources. In Gallo et al. (2022), the consideration of relative changes in resources is based on the following assumptions: two individuals experiencing the same loss of resources in the same period of time will perceive a different level of insecurity if they start from different resource levels; individuals are more likely to judge changes in their economic status in relative terms, as they are used to doing with wage and salary increases (usually expressed in relative terms). Moreover, indices based on relative changes are independent of the order of magnitude of the phenomenon and the unit of measurement.

We consider a population of N individuals, $N \in \mathbb{N}$, observed over $T+1$ points in time, $T \in \mathbb{N}$, where 0 denotes the current point in time and $-T$ is the furthest point in time $(-T, \ldots, 0)$. i denotes the individual $(i = 1, \ldots, N)$and $x_i = (x_{i,-T}, \ldots, x_{i,0})$ is its stream of value for resource X. The resource values cannot be negative due to the use of logarithmic transformation.

The class of measures of individual economic insecurity suggested by Gallo et al. (2022) is a sequence of functions $LI_R = \left\langle LI_R^T \right\rangle_{T \varepsilon \mathbb{N}}$, where for each $T \in \mathbb{N}$, $LI_R^T : \mathbb{R}_{++}^{T+1} \to \mathbb{R}$ is a function that assigns an insecurity value to each individual resource stream $x_i \in \mathbb{R}_{++}^{T+1}$:

$$LI_R^T(x_i) = l_0 \sum_{\substack{t \in \{1,\ldots,T\} \\ x_{i,-t} > x_{i,-(t-1)}}} \delta^{t-1} \ln\left(\frac{x_{i,-t}}{x_{i,-(t-1)}}\right) + g_0 \sum_{\substack{t \in \{1,\ldots,T\} \\ x_{i,-t} < x_{i,-(t-1)}}} \delta^{t-1} \ln\left(\frac{x_{i,-t}}{x_{i,-(t-1)}}\right) \quad (1)$$

The indices are given by a weighted sum, with weights denoted by l_0 and g_0 $(l_0, g_0 \in \mathbb{R}_{++})$, of the sum of weighted relative losses and the sum of weighted relative gains occurring between two consecutive points in time. Losses and gains are included in the formula as the logarithmic transformation of the relative changes, because of the properties of the logarithm. δ is an inter-temporal weight that must take a value in the specific range $(0, \min\{l_0/g_0; g_0/l_0\})$ in order to give an increasingly low relevance to relative changes going back in time (Bossert et al., 2022). Moreover, the weight given to gains (g_0) must be lower than the weight given to losses (l_0), assuming that losses have a greater impact than gains on the individual perception of economic insecurity. Such conditions on the parameters (δ, g_0, l_0) are necessary to ensure that the indices respect some desirable properties.

To define the cross-sectional component, we choose the comparison at the current time, in relative terms, between the resource level of the individual and a representative value in the peer-relevant reference group. Among the possible representative values, we choose to use the median, for the following reasons: it is often used as a benchmark in the literature on poverty and relative deprivation and it is not affected by the presence of outliers. However, alternative representative values could be considered. An example is the mean. Thanks to its decomposition property, the weighted average of group means gives the overall mean.

Furthermore, we propose to consider the logarithm of the ratio between the median of the group and the individual's resource value. The use of the logarithm enables us to capture relative changes better than the generic percentage change (Törnqvist et al., 1985) and makes the second component of the composite index in line with the first one. We assume

that the higher the ratio, with a positive (negative) value, the more individuals perceive their economic status as disadvantaged (advantaged) compared to that of their peers.

We consider the population as divided in J, $J \in \mathbb{N}$, mutually exclusive and overall exhaustive classes that represent the reference groups. j denotes the classes $(j = 1, \ldots, J)$ and $N_1, \ldots, N_j, \ldots, N_J$ represents the number of individuals in each class $\left(\sum_{j=1}^{J} N_j = N\right)$. Individual $i.th$ belonging to reference group $j.th$ makes a comparison with the other individuals belonging to the same class at the current time 0. We denote by $Me_{j(i),0}$ the median of class $j.th$ that includes individual $i.th$, at the current time, and by $x_{j(i),0} = \left(x_{1j,0}, \ldots, x_{ij,0}, \ldots x_{N_j j,0}\right)$ the resource levels for individuals belonging to class $j.th$ (including individual $i.th$) at the current time. The cross-sectional component is defined as a function that assigns an insecurity value to each individual $i.th$ belonging to reference group $j.th$, by considering the sequence $x_{j(i),0} \in \mathbb{R}_{++}^{N_j}$, $CSI : \mathbb{R}_{++}^{N_j} \to \mathbb{R}$:

$$CSI\left(x_{j(i),0}\right) = \ln\left(\frac{Me_{j(i),0}}{x_{ij,0}}\right) \tag{2}$$

To identify an individual's reference group, we need to define the individual's peers. Several studies have highlighted the importance of identifying an appropriate reference group for understanding the determinants of well-being. For example, Blanchflower and Oswald (2004) consider geographical areas to define the reference group using the US states, while McBride (2001) adopts an age class characterization to define classes. In this paper, we propose to use a hybrid approach, considering both the geographical area and some socio-demographic characteristics of the individual, as also suggested in Budría and Ferrer-i-Carbonell (2019) and D'Ambrosio et al. (2020). A more detailed discussion of the choice of reference group is provided in Sect. 4.1.

To combine the two components, the choice of a weighted mean has often been used in the literature (Nardo et al., 2005; De Muro et al., 2011; Gutierrez Sanin et al., 2013). The composite inter-temporal indices that we propose use the information included in the union of x_i and $x_{j(i),0}$, $x_i^* = x_i \cup x_{j(i),0}$, which has a common element, the resource of individual $i.th$ at the current time. Therefore, the class of indices may be defined as a function $CI^T\left(x_i^*\right) : \mathbb{R}_{++}^{T+N_j} \to \mathbb{R}$ that assigns an insecurity value to each vector $x_i^* \in \mathbb{R}_{++}^{T+N_j}$:

$$CI^T\left(x_i^*\right) = \epsilon LI_R^T\left(x_i\right) + (1-\epsilon)CSI\left(x_{j(i),0}\right) \tag{3}$$

where $\epsilon \in [0,1]$ represents a constant weight for all individuals.

3.2 A Proposal for Setting ϵ

The choice of weights in a composite index is a relevant issue as it can significantly affect the results (Greco et al., 2019). Some authors give the same weight (0.5) to the two components when suggesting an inter-temporal index (Ceriani & Gigliarano, 2015). Romaguera-de-la Cruz (2020) combines several indicators giving each of them a weight proportional to the sample units below a meaningful threshold for that indicator.

In our case, we consider that many studies in the literature on economic insecurity validate the use of subjective measures, obtained from subjective survey questions on the perception of one's own economic condition. Many surveys on households' conditions

ask respondents to rate their level of economic security on a satisfaction scale (Rohde & Tang, 2018; Rebechi & Rohde, 2023; Clark & Lepinteur, 2022). Therefore, as an attractive alternative, we consider using the weight ϵ that maximizes the correlation ratio η^2, which measures the correlation between the dispersion of the individual scores derived from the composite index within the categories defined by a subjective question, and the total score dispersion. In this way we "align" the class of composite indices with the perception of insecurity captured by the subjective question. This approach offers a meaningful method for integrating subjective measures into a composite index, presenting a novel approach to defining weights in this context.

Denoting by g, $g = 1, \ldots, G$, the categories defined by a subjective question A on the perception of one's own economic condition, the correlation ratio is given by the ratio between the deviance of the individual scores between the categories $(SSB)$and the total deviance of the scores (SST):

$$\eta^2 = \frac{SSB}{SST}$$

Maximizing η^2, corresponds to minimizing the within groups variance of the scores.

For the sake of simplicity, in this sub-section we write the class of composite inter-temporal indices as $CI = \epsilon LI + (1 - \epsilon)CSI$.

The variance of CI within category $g.th$ can be written as follows:

$$var_g(CI) = \epsilon^2 var_g(LI) + (1-\epsilon)^2 var_g(CSI) + 2\epsilon(1-\epsilon)\, cov_g(LI, CSI)$$

where $var_g(\bullet)$ and $cov_g(\bullet, \bullet)$ denote the variance and the covariance within category $g.th$, respectively.

Assuming that the covariance between the two components is approximately 0 within the categories, it is possible to write the total within variance of the scores as follows:

$$var(CI) \cong \epsilon^2 \sum_{g=1}^{G} var_g(LI) + (1-\epsilon)^2 \sum_{g=1}^{G} var_g(CSI)$$

minimizing this variance with respect to ϵ we obtain, after some steps, the following result for ϵ:

$$\epsilon = \frac{\sum_{g=1}^{G} var_g(CSI)}{\sum_{g=1}^{G} var_g(CSI) + \sum_{g=1}^{G} var_g(LI)}$$

which, replaced in (3), gives a higher weight to the longitudinal component the larger the cross-sectional variance is compared to the longitudinal one, and vice-versa[1].

[1] If the covariance between the two components within categories cannot be assumed to be close to 0, the result forϵ is:

$$\epsilon = \frac{\sum_{g=1}^{G} var_g(CSI) - \sum_{g=1}^{G} cov_g(LI, CSI)}{\sum_{g=1}^{G} var_g(CSI) + \sum_{g=1}^{G} var_g(LI) - 2\sum_{g=1}^{G} cov_g(LI, CSI)}$$

3.3 The Properties

From an analytical point of view, it is important that the proposed class of indices satisfies a set of desirable properties, in particular: *Gain-Loss Monotonicity*, *Proximity Monotonicity*, *Stationarity*, *Quasilinearity* and *Scale Invariance*[2]. The first four properties refer to the longitudinal part of the indices and are not affected by the comparison with peers, so we will neglect the cross-sectional component of the indices when stating these properties. In addition, to simplify the notation, we ignore the subscripts i and j for the first four properties. We use 1_m to denote a vector consisting of $m \in \mathbb{N} \setminus \{1\}$ values equal to one.

The first two properties are related to the fluctuations in the resource stream. The first one implies that a resource stream with a gain between two consecutive points in time produces a lower level of insecurity than a stream with no changes between the two points in time. Similarly, a resource stream with a loss between two consecutive points in time produces a higher level of insecurity than a stream with no changes.

Property (Gain-loss Monotonicity). For all $t \in \mathbb{N}$, for all $p, q \in \mathbb{R}_{++}, (p > q$ to guarantee that $p - q \in \mathbb{R}_{++})$,

$$I^t\left(p+q, p1_t\right) > I^t\left(p, p1_t\right) > I^t\left(p-q, p1_t\right).$$

The second property relates to the timing of the fluctuations. Fluctuations that occur further in the past should have less of an impact on insecurity scores than fluctuations that occur closer to the present time of 0. For example, a "first up and then down" fluctuation in the stream between time $-t$ and $-(t-1)$ is associated with a lower level of insecurity than a "first up and then down" fluctuation occurring between time $-(t-1)$ and $-(t-2)$.

Property (Proximity Monotonicity). For all $t \in \mathbb{N}$, for all $p, q \in \mathbb{R}_{++}$, ($p > q$ to guarantee that $p - q \in \mathbb{R}_{++}$),

$$\begin{gathered} I^{t+2}\left(p, p, p+q, p1_t\right) > I^{t+2}\left(p, p+q, p, p1_t\right) > I^{t+2}\left(p, p, p, p1_t\right) > \\ I^{t+2}\left(p, p-q, p, p1_t\right) > I^{t+2}\left(p, p, p-q, p1_t\right). \end{gathered}$$

The next property is essential when dealing with the inter-temporal nature of the class of measures, and concerns the possibility of decomposing them and thus comparing resource streams of different lengths. It states that the level of insecurity associated with the stream $x \in \mathbb{R}_{++}^{T+1}$ can be expressed as a quasilinear function of the level of insecurity associated with the stream of the T most recent points in time $\left(x_{-(T-1)}, \ldots, x_0\right)$ and a function of the two quantities x_{-T} and $x_{-(T-1)}$.

Property (Quasilinearity). For all $T \in \mathbb{N} \setminus \{1\}$, there exists a function $F_{++}^T : \mathbb{R}^2 \to \mathbb{R}$, such that for all $x \in \mathbb{R}_{++}^{T+1}$,

$$I^T(x) = I^{T-1}\left(x_{-(T-1)}, \ldots, x_0\right) + F^T\left(x_{-T}, x_{-(T-1)}\right).$$

[2] Proofs can be found in the Appendix A.

Stationarity is a standard feature of indices that use geometric discounting. Due to the structure of the indices, the current period cannot be shifted forward or backward, so the resource level of the current time is repeated at additional points in time.

Property (Stationarity). For all $r \in \mathbb{N}_0$, an increasing function $G^r : \mathbb{R} \to \mathbb{R}$ exists, such that for all $t \in \mathbb{N}_0$ and for all $p, p', s \in \mathbb{R}_{++}$,

$$I^{(t+2+r)}\left(p, p', s1_{t+1}, s1_r\right) = G^r\left(I^{t+2}\left(p, p', s1_{t+1}\right)\right).$$

The fifth property, Scale Invariance, can be considered for both components of the indices. It is related to relative changes. According to this property, if all the resource levels considered in the class of measures vary due to the same scale factor b, the level of insecurity remains unchanged.

Property (Scale Invariance). For all $T \in \mathbb{N}$, for all $x_i^* \in \mathbb{R}_{++}^{T+N_j}$ and for all $b \in \mathbb{R}_{++}$:

$$I^T\left(bx_i^*\right) = I^T\left(x_i^*\right).$$

4 Data

We use longitudinal data taken from the EU Statistics on Income and Living Conditions (EU-SILC). EU-SILC provides information on income, poverty, social exclusion, and other living conditions. The longitudinal part of the sample is observed over a period of 4 years, hence T=3 in our application.

We focus on ten European countries, Italy, France, Sweden, Greece, Finland, Belgium, Denmark, Poland, Spain, and Austria, in order to represent different European regions. We consider the period from 2014 to 2019 (reference period of income). As an individual resource, we use the household equivalent disposable income, equivalized according to the modified OECD equivalence scale. This income is also deflated using the Harmonized Consumer Price Index (HCPI) provided by Eurostat Statistics, to allow comparisons over time.

To compute ϵ, we follow the approach suggested in Sect. 3.2. We rely on a subjective survey question that has already been used in previous applications (for example, Romaguera-de-la Cruz, 2020), asking "*Thinking of your household's total income, is your household able to make ends meet, namely, to pay for its usual necessary expenses?"*. The possible answer has six modalities ranging from "with great difficulty" to "very easily"[3].

4.1 The Reference Group

The choice of the reference group is crucial for a proper definition of the cross-sectional component. Ideally, the closest peers of each individual should be identified. However, this is a rather difficult task given the personal information available in survey datasets.

[3] Possible answers: (1) *With great difficult; (2) With difficulty; (3) With some difficulty; (4) Fairly easily; (5) Easily; (6) Very Easily.*

Two main approaches to defining the reference group for comparisons have been proposed in the literature on well-being (Budría & Ferrer-i-Carbonell, 2019). Some authors suggest defining the peers based on geographical proximity. For example, Clark et al. (2009b); Dittmann and Goebel (2010) use neighborhoods for the evaluation of the drivers of life satisfaction; Di Tella et al. (2003) consider countries when studying how macroeconomic movements affect the happiness of nations; and Blanchflower and Oswald (2004) consider US states to analyze the relationship between growth and well-being. Other authors consider specific individual characteristics such as age, gender, educational level and type of job. For example, Clark (2003) uses individual labor market conditions (being unemployed), finding that the impact of unemployment on well-being matters less when it is shared; Clark et al. (2009a) use co-workers to study how job satisfaction reacts to the presence of a better-paid reference group; McBride (2001) considers the group of people up to five years younger or older than the individual, to study the effect of relative income on subjective well-being.

However, other authors suggest the adoption of a hybrid approach when studying the role of "comparison-income" in assessing individual happiness (Ferrer-i-Carbonell, 2005; Budría & Ferrer-i-Carbonell, 2019, D'Ambrosio et al., 2020).

Following the suggestion of Budría and Ferrer-i-Carbonell (2019), we consider both the most detailed geographical reference available in the data, NUTS1, and the following individual characteristics: the gender, the age in classes (up to 30, 31–40, 41–50, 51–60, over 60) and the educational level (primary education, lower secondary education, upper secondary education, post-secondary non-tertiary education, and tertiary education).

5 Application to EU-SILC Data

The composite inter-temporal index is calculated by setting the parameters of the longitudinal component, as follows: $g_0 = 15/16, l_0 = 1$ and $\delta = 0.9$. We choose these values because we assume that losses have a higher impact than gains on individual perceptions of economic insecurity. Moreover, lower values for δ would not give enough relevance to past fluctuations. This choice is in line with the branch of literature opened up by Tversky and Kahneman (1991) and with previous empirical applications (Bossert et al., 2022; Gallo et al., 2022).

The weight ϵ varies by country (Table B1 in Appendix B). In 2019, for example, it ranges from a minimum of 0.491 for Poland to a maximum of 0.622 for Denmark.

5.1 Analysis of the Two Components

In this sub-section we compare the two components of the composite inter-temporal index to highlight their contribution to the measurement of economic insecurity provided by the composite index.

Figure 1 shows a scatterplot for each of the countries considered, where individuals are plotted according to their scores on the two components (the longitudinal component on the x-axis and the cross-sectional component on the y-axis) in 2019.

The clouds of points that extend across all four quadrants highlight the presence of cases with both concordant and discordant signs of the two components in all the countries. Moreover, in several countries, such as Italy, Greece, Spain, Austria, Poland and Belgium, a

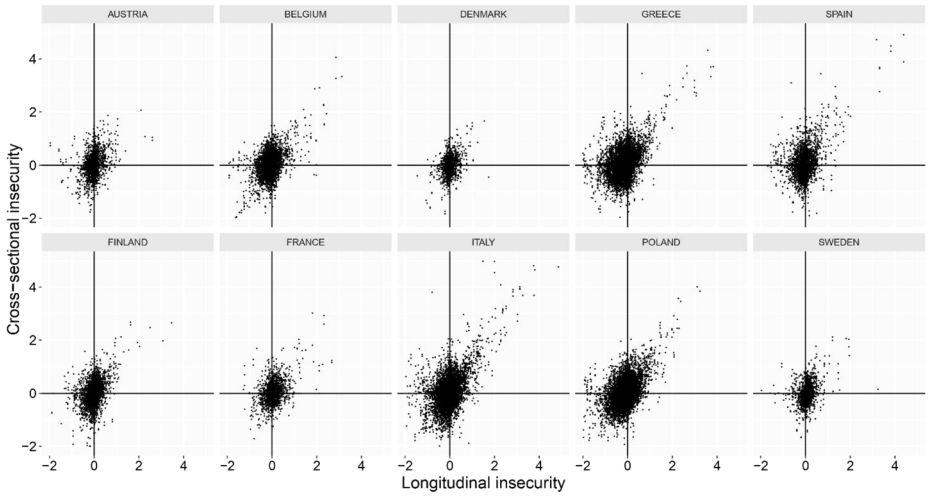

Fig. 1 Individuals plotted according to the longitudinal insecurity score (X axis) and the cross-sectional insecurity score (Y axis) by country (2019). *Source*: Own elaboration on EU-SILC longitudinal data

group of outliers shows very similar values in the first quadrant, highlighting the presence of extremely insecure individuals on both dimensions. The correlation coefficient between the two components shows a significant but not extreme concordance, ranging from 0.29 in Sweden to 0.48 in Italy.

Figure 2 shows the weighted means of the two components (Horwitz-Thompson estimator calculated taking into account the weights of the longitudinal survey) obtained for the countries for the first (top graph) and last (bottom graph) year of the period considered, in order to highlight possible changes over this period.

We can see that Southern European countries (Greece, Spain and Italy) appear to be the most insecure on average according to the longitudinal component (x-axis), while Northern and Central European countries are relatively less insecure according to this component, in 2014. This result is in line with previous findings obtained for the same year. For example, Cantó et al. (2020) find that Mediterranean countries stand out as the most insecure compared to Eastern, Central and Northern countries in 2014, according to a multi-dimensional index of insecurity obtained using a counting approach.

The cross-sectional component (y-axis) shows smaller differences between countries, although it is interesting to note that Denmark stands out as the most insecure country, while Poland appears to be the least insecure on average according to this component.

The graph obtained for 2019 shows noticeable changes over time, especially for the longitudinal component. The southern European countries show a decrease in insecurity over the period considered. Greece, previously the most insecure country in 2014, transitions to the least insecure in 2019. Italy and Spain also experience a reduction in the longitudinal component, although less than Greece. Conversely, the countries of northern and central Europe experience small changes, with the exception of Sweden, which moves from being among the least to the most insecure countries longitudinally.

With regard to cross-sectional insecurity, it can be seen that Spain in particular, where longitudinal insecurity is improving, is becoming more insecure cross-sectionally. Among

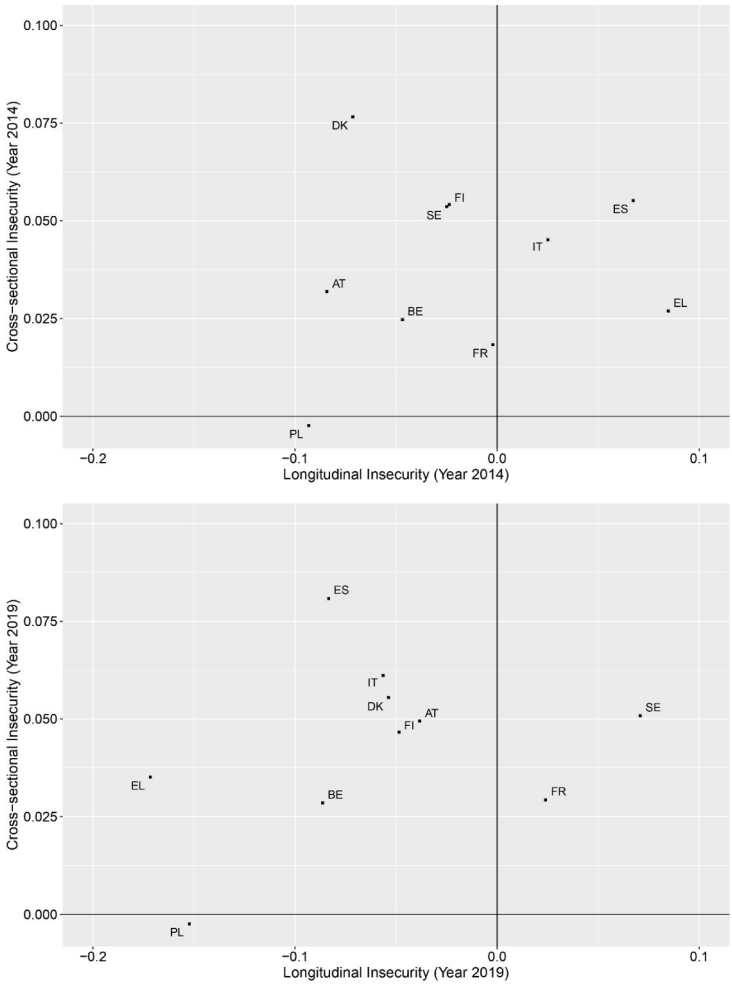

Fig. 2 Countries plotted according to the weighted means of the longitudinal component scores (x-axis) and the cross-sectional component scores (y-axis). Country Labels: AT=Austria, BE=Belgium, DK=Denmark, EL=Greece, ES=Spain, FI=Finland, FR=France, IT=Italy, PL=Poland, SE=Sweden. *Source*: Own elaboration on EU-SILC longitudinal data

the northern European countries, Finland and Sweden remain almost at the same level, while Denmark experiences a decrease and approaches the level of Finland and Sweden.

5.2 A Comparison with Other Economic Insecurity Indices

In this section we compare the composite inter-temporal indices with other measures previously proposed in the literature. We consider the Hacher et al. (2014) index, and the Bossert et al. (2022) and Gallo et al. (2022) (LI_R^T) classes of indices. To this purpose we focus

on the last year of the period considered and one country, Italy, as very similar results are obtained for all the countries considered in the previous sections[4].

LI_R^T indices represent the longitudinal component of CI^T indices, while in Bossert et al. (2022) indices, changes in past resource levels are included as absolute pairwise differences. To compute these indices, we use the same previously discussed parameter values ($T = 3, g_0 = 15/16, l_0 = 1$ and $\delta = 0.9$).

In Fig. 3, the individual scores computed using CI^3 are compared with those obtained using LI_R^3 and Bossert et al. (2022) indices through scatterplots. CI^3 and LI_R^3 scores draw a stretched cloud of points, as expected. The correlation coefficient ρ between the two indices is 0.86. The two indices tend to point out the same individuals as the most insecure and the least insecure, even though some exceptions may be observed. Larger differences may be noticed between CI^3 and Bossert et al. (2022) indices ($\rho = 0.65$). Even in this case the points extend above all across the third and first quadrants. Both indices provide low scores (in their respective scale) for many cases. However, many individuals that appear among the most economic insecure according to CI^3 index do not rank similarly under the Bossert et al. (2022) index, and vice-versa. This result highlights that these two indices measure economic insecurity in different ways, capturing different aspects as they move from different premises and different definitions of economic insecurity.

We would like to highlight here one difference between CI^T indices and the other two classes of indices. LI_R^T and Bossert et al. (2022) classes assign the same insecurity score to every member of a household, while CI^T indices may provide slightly different scores for them, due to the definition of the cross-sectional component. This is a consequence of the assumption underlying CI^T that the individual insecurity is also affected by the comparison with the others.

To compare CI^3 with Hacker et al. (2014) index, we use the correlation ratio η^2, as Hacker et al. (2014) index is a dummy variable, set equal to 1 if the individual meets a set of conditions[5] and 0 otherwise. We compute a simpler version of the original Hacker et al. (2014) index due to lack of information on some of those conditions in our dataset. We set the index equal to 1 if a sharp drop (over 25%) in the household equivalent disposable income occurs over the past year. The correlation ratio between the two indicators is quite low (0.14). However, when computing the weighted means of the CI^3 for the two groups of individuals having Hacker index equal to 0 and 1, two very different means are obtained, respectively −0.07 and 0.58. This suggests a fundamental coherence between the two indices, even though *CI* is more complex and hence able to capture more aspects of economic insecurity.

5.3 Comparison Between EU-Countries

Figure B1 in Appendix B presents a boxplot for each of the countries considered, showing the distribution of the *CI* scores obtained for 2019. The boxplots show very similar distributions in all the countries, with insecurity scores mostly concentrated around the median, which is always close to 0. The boxplots also highlight the presence of outliers in all the countries, especially in the upper tail, as already noted in the analysis of the two components

[4] Results for other countries are available from the authors upon request.

[5] The set of conditions include a drop of 25% in disposable income, a lack of an adequate financial safety net and a large MOOP (out-of-pocket medical spending) spending shock.

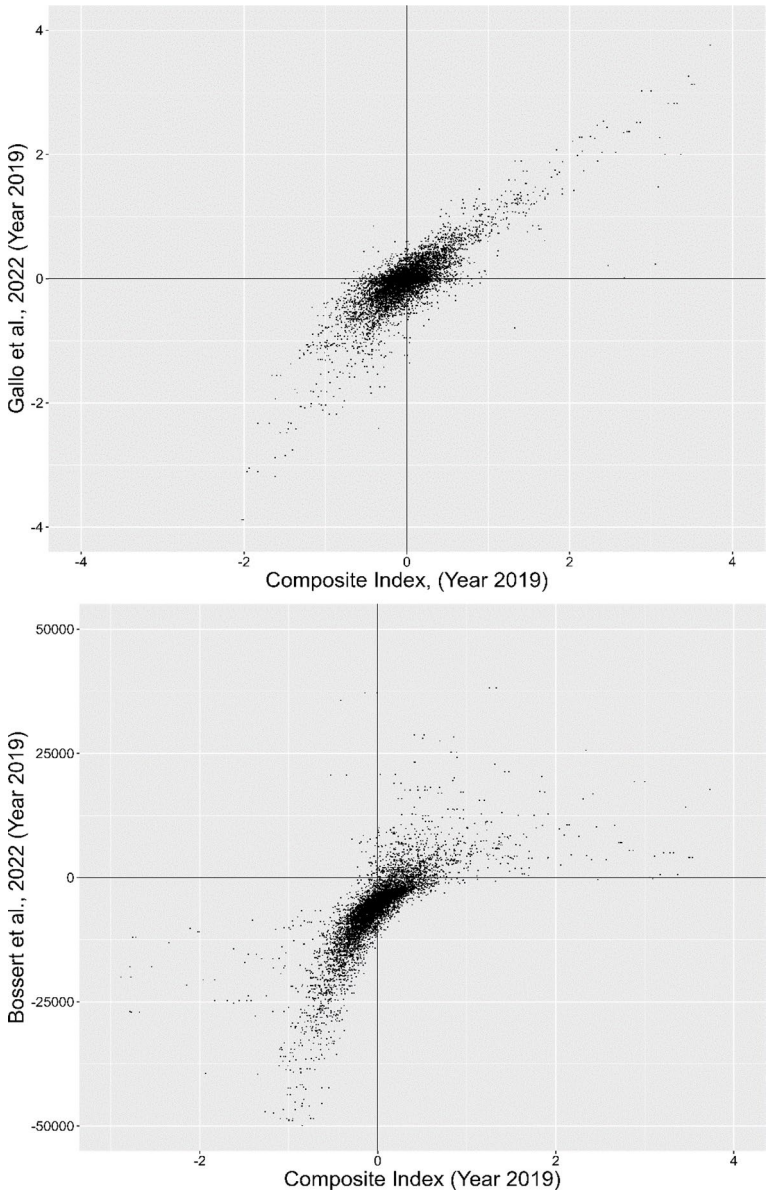

Fig. 3 Comparison between individual economic insecurity scores in 2019 in Italy, as defined in *CI* and *LI* (top graph), and *CI* and Bossert et al. (2022) (bottom graph) *Source*: own elaboration on EU-SILC longitudinal data

(Sect. 5.1). Upper-tail outliers (extremely insecure individuals) are notably evident for Austria, Italy and Spain, whereas lower-tail outliers (slightly insecure individuals) are particularly noticeable for Greece. Furthermore, insecurity scores appear to be more concentrated around the median in Denmark, France and Sweden than in the other countries.

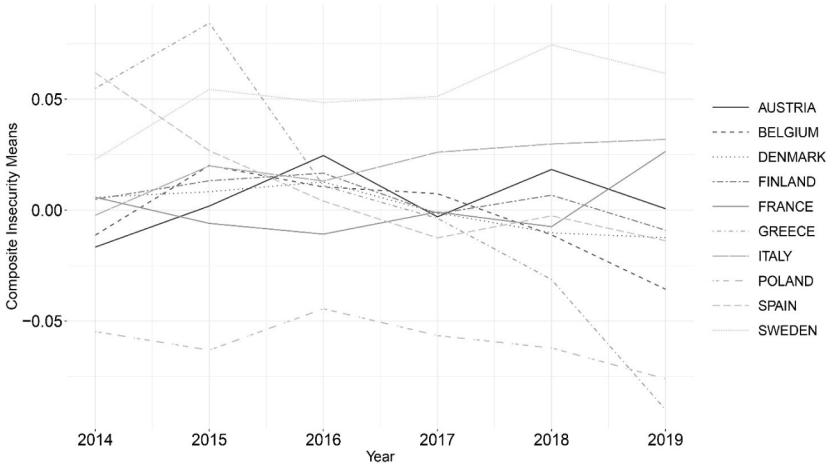

Fig. 4 Weighted means of *CI* index from 2014 to 2019 in the EU countries. *Source*: Own elaboration on EU-SILC longitudinal data

Figure 4 compares countries on the basis of the evolution over time of the weighted means of the composite inter-temporal index. The graph shows some interesting and somewhat unexpected results. For example, Greece initially ranks among the most insecure countries on average (2014 and 2015), subsequently experiencing a substantial reduction in insecurity, ultimately becoming the least insecure country in 2019. Spain, after being the most insecure country in 2014, starts to decrease and then stabilizes at intermediate levels. Sweden shows the opposite trend, an overall increase of insecurity from 2014 to 2019 that peaked in 2018. Poland remains the least insecure country on average (until 2018), with an overall decreasing trend. Italy shows a slightly increasing trend that places it as the second most insecure country since 2017.

These results obviously depend on the structure of the index and are partially influenced by the trends over time of the household income. To illustrate this effect, the annual change in the weighted mean of the household equivalent disposable income, obtained for the countries considered based on EU-SILC data, are reported in Table B2 in Appendix B. Greece, for example, experienced a noteworthy increase in the mean income, from 2014 to 2019 (about 13%), also thanks to the assistance of the financial aid provided by the EU and the International Monetary Fund (Maris et al., 2022). Notably, the last tranche of EU financial assistance in the period 2015–2018 significantly helped the Greek economic situation (European Commission, 2023).

The mean income of Poland also increases every year in the period considered, with an overall growth of about 27%. This may also be due to its efficient use of the European funds since its accession to the EU (Kapil et al., 2013) and its good performance during the 2009 economic crisis as reported by Gradzewicz et al. (2018).

On the other hand, in countries such as Sweden and France, where the mean disposable income decreased in the period considered (-9.8% from 2014 to 2018 in the case of Sweden, -5.19% from 2018 to 2019 in the case of France), an increase in economic insecurity arises from Fig. 4.

To understand the importance given by the index to the longitudinal component (the most variable over time of the two components, see Sect. 5.1) in the different countries, we can observe the values obtained for ϵ (Table B1 in Appendix B). ϵ values tend to range between 0.4 and 0.6 for all countries, even for Greece and Poland, except for Greece and 2017 where ϵ equals 0.68.

5.4 Economic Insecurity and Other Well-Being Measures

In this sub-section, we compare the average results obtained for the proposed index of economic insecurity with some indices commonly used to measure poverty, inequality, material deprivation and work intensity. The aim is to highlight the differences between the information provided by the proposed measure and other very popular measures of economic well-being: four income-based measures of poverty and inequality, a measure of material deprivation and a measure of work intensity. In particular, we consider: the At Risk of Poverty Rate (ARPR), which represents the share of the population below the poverty threshold and measures the poverty incidence; the Relative At Risk of Poverty Gap (RARPG), which compares the median income of the poor with the poverty threshold, therefore measuring the intensity of poverty; the Gini coefficient, which is the most popular measure of economic inequality; the quintile share ratio (S80/S20), which is an index of inequality calculated by comparing the total income of the richest 20% and the poorest 20% of the population; the material deprivation rate, given by the share of the population that cannot afford at least three items among nine items considered necessary to lead an adequate life[6]; the very low work intensity rate, which is the share of the population aged less than 65 years living in households with very low work intensity[7].

The information regarding the well-being measures reported in Table 1 are taken from Eurostat Statistics (2022) and refers to 2019. Table 1 also reports the ranking of countries based on the measures considered.

With regard to the income-based measures, Southern European countries rank at the top for poverty and inequality, while the most insecure country, on average, is Sweden, followed by Italy and France. In fact, the economic insecurity index is built to capture rather different aspects of well-being that are not accounted for in the poverty and inequality measures. The material deprivation index substantially confirms the ranking showed by poverty and inequality measures, with southern European countries at the top and northern European countries at the bottom. The low work intensity index, instead, provides a different ranking, with the lowest work intensity in Belgium, Greece and Spain and the highest in Poland, Austria and France. Such a discrepancy between the work intensity index and the poverty and inequality measures can be explained by the different average levels of income and the different welfare systems in the considered countries.

The case of Greece is emblematic for the interpretation of the economic insecurity index. Greece shows very high levels of poverty, inequality, material deprivation and low work intensity, while it is the least insecure on average thanks to the increasing trend in

[6] The nine items are: (1) to pay their rent, mortgage or utility bills; (2) to keep their home adequately warm; (3) to face unexpected expenses; (4) to eat meat or proteins regularly; (5) to go on holiday; (6) a television set; (7) a washing machine; (8) a car; (9) a telephone.

[7] Households where the members of working age worked a working time equal or less than 20% of their total work-time potential.

Table 1 Insecurity and other well-being measures: a comparison between EU countries (2019)

	Insecurity		ARPR		Gini		S80/S20		RARPG		Mat. Dep.		Low Work Intensity	
	Value	*Rank*	*Value*	*Rank*	*Value*	*Rank*	*Value*	*Rank*	*Value*	*Rank*	*Value*	*Rank*	*Value*	*Rank*
Austria (AT)	0.001	4	13.3	8	27.5	7	4.17	7	23.9	4	2.5	7	6.6	9
Belgium (BE)	-0.036	8	14.8	6	25.1	9	3.61	10	16.3	9	5.0	4	12.8	1
France (FR)	0.026	3	13.6	7	29.2	4	4.27	6	16.5	8	8.4	2	7.1	8
Poland (PL)	-0.076	9	15.4	5	28.5	5	4.37	4	22.0	5	4.7	5	5.0	10
Denmark (DK)	-0.012	6	12.5	9	27.5	7	4.09	8	18.8	7	4.3	6	9.5	5
Sweden (SE)	0.062	1	17.1	4	27.6	6	4.33	5	21.7	6	1.9	9	8.3	6
Finland (FI)	-0.009	5	11.6	10	26.2	8	3.69	9	14.9	10	2.1	8	8.1	7
Greece (EL)	-0.090	10	17.9	3	31.0	3	5.11	3	27.0	3	23.9	1	12.7	2
Spain (ES)	-0.014	7	20.7	1	33.0	1	5.94	2	29.1	2	8.0	3	10.9	3
Italy (IT)	0.032	2	20.1	2	32.8	2	6.01	1	30.0	1	8.0	3	9.6	4

Insecurity: measured by the weighted mean of CI individual scores

ARPR: the share of individuals with an equivalized disposable income below the at-risk-of-poverty threshold, which is set at 60% of the national median equivalized disposable income

Gini: the Gini coefficient, defined as the relationship of cumulative shares of the population arranged according to the level of equivalized disposable income, to the cumulative share of the equivalized total disposable income received by them

S80/S20: the ratio of total income received by the 20% of the population with the highest income (highest quintile) to that received by the 20% of the population with the lowest income (lowest quintile)

RARPG: the ratio between the median of the equivalized total net income of individuals below the at-risk-of-poverty threshold and the at-risk-of-poverty threshold

Mat. Dep.: the share of the population that cannot afford at least three items among nine items considered necessary to lead an adequate life

Low Work Intensity: the share of the population aged less than 65 years living in households with very low work intensity

Source: Own elaboration on EU-SILC longitudinal data for weighted mean of individual CI scores, and Eurostat for at risk of poverty rate, Gini, S80/S20 (quintile share ratio), relative at risk of poverty gap, material deprivation and low work intensity

the incomes of Greek citizens that characterized the period considered, as discussed in the previous section. After years of deep economic crisis, Greece shows significantly better economic data compared to the Eurozone average. Many economic indicators highlight its significant resilience. Greece's GDP growth was among the highest in the EU from 2017 to 2019 (Maris et al., 2022). Furthermore, in Greece the unemployment rate decreased (about 6%, according to Eurostat, from 2016 to 2019), while wage pressure increased. Therefore, the economic insecurity index points out the resilience of this country in the period considered, despite its poverty and inequality levels remain higher than in the other countries in 2019.

Sweden results to be the most insecure country on average. It is also possible to notice a remarkable difference in the ARPR of Sweden compared to the values resulting for the other Northern European countries. The Swedish poverty rate is much higher (17.1) than those resulting for Denmark and Finland (12.5 and 11.6, respectively), while it is close to that of Greece (17.9). These findings may be also explained by the phenomenon of "temporary poverty" that characterizes above all some Northern European countries (Ranci et al., 2021). The concept of temporary poverty accounts for individual income volatility: households are classified as temporarily poor if their income temporarily drops below the poverty threshold, as defined in Western et al. (2012). These authors argue that temporary poverty is more prevalent in countries with lower income inequalities and stronger social protections. Furthermore, in these countries, minimum income programs enable the temporarily poor to recover quickly (Kangas & Kvist, 2013). Our index of economic insecurity is certainly affected by this phenomenon for both components, as the longitudinal component takes into account past income fluctuations and the cross-sectional component is based on a comparison with the median, which can be seen as the poverty threshold of the reference group.

6 Economic Insecurity in Subpopulations

In this section, we carry out a comparison of economic insecurity in subpopulations in order to identify particular groups where economic insecurity is more severe, according to the suggested index. We focus on one country, Italy, and the last year of the period considered (2019). The gender, age-class, marital status, labor market status (considering the modalities "at work", "unemployed", "in retirement" and "other inactive"), the size of the individual's household, and its household's disposable equivalized income in classes, are selected for this analysis. Income classes are defined based on the quartiles of this variable's distribution and rounding these values to the nearest thousand.

Table 2 reports the weighted means calculated for subgroups using the longitudinal weights. Results highlight that males are less insecure on average than females. Moreover, economic insecurity shows a non-linear relationship with age, as it reduces moving from the first age class (under 40 years old) to the intermediate age class (from 51 to 60 years old) and then increases again, with individuals aged 71 and above experiencing the highest level of economic insecurity on average. Being married appears to mitigate economic insecurity. With regard to labor market conditions, unemployed individuals exhibit the highest subgroup mean as expected, followed by the class "other inactive". Retired people are less economically insecure compared to "other inactive". This result also depends on the characteristics of the Italian public pension system, that is considered to be one of the most

Table 2 *CI* sub-groups means by demographic and economic characteristics in Italy (2019)

Individual Charateristics	Classes	CI (Weighted Mean)
Gender:		
	Male	-0.0075
	Female	0.0025
Age Classes:		
	Age ≤ 40	-0.0036
	41 ≤ Age ≤ 50	-0.0096
	51 ≤ Age ≤ 60	-0.0328
	61 ≤ Age ≤ 70	0.0141
	Age ≥ 71	0.0202
Marital Status:		
	Non Married	0.0184
	Married	-0.0163
Labor Market Condition:		
	At Work	-0.0529
	Unemployed	0.1078
	In retirement	0.0087
	Other Inactive	0.0453
Income Classes:		
	(0 ; 12,000)	0.1999
	[12,000 ; 17,000)	0.0431
	[17,000 ; 24,000)	-0.0403
	[24,000 ; 176,700]	-0.2075
Household size:		
	1	0.1048
	2	-0.0430
	3	-0.0557
	4	0.0183
	5 or more	0.0742

Source: Own elaboration on EU-SILC longitudinal data

generous "pay-as-you-go" systems in EU, despite the recent pension reforms (Franco & Tommasino, 2020).

The economic insecurity decreases as the income class increases. The income in classes is the individual characteristic for which the highest differences between the economic insecurity means are observed. It is, as expected, the characteristic most related to the economic insecurity. Similar findings come from Ranci et al. (2021), where an inverse relationship between income and long term insecurity is found.

Finally, the economic insecurity shows a non-linear relationship with the household size. "One-person households" and "households with 5 or more members" are the most insecure categories, while households having two or three members are the least insecure. This pattern can be due to the greater presence of non-working individuals or young workers in large households. Conversely, households with young workers show less economic insecurity, as they contribute with additional income sources (Romaguera de la Cruz, 2020).

7 Conclusions

In this paper we propose, for the first time, a class of composite inter-temporal indices to measure economic insecurity. The approach proposed in this paper allows for a continuous individual score of economic insecurity through a comprehensive measure that includes two important dimensions of economic insecurity, as it considers both a longitudinal and a cross-sectional component. The longitudinal component takes into account the fluctuation of individuals' resources over time and their ability to recover, while the cross-sectional component represents the perception of one's own economic situation compared to others at the current time.

In addition, we propose a novel approach to combine the two components, taking advantage of the availability of subjective measures of one's own economic conditions. These subjective measures are widely used in the branch of literature that focuses on measuring economic insecurity based on subjective self-assessments. The class of indices that we propose is proven to satisfy a set of desirable properties.

The application of an index of the proposed class to longitudinal EU-SILC data from several EU countries shows how our proposal allows us to distinguish the different aspects of economic insecurity. Moreover, our proposal brings some new insights into individuals' perceptions of well-being, which could be considered in addition to the well-established measures of poverty and inequality. The index provides useful information that, when combined with the information provided by traditional measures of well-being, can provide a comprehensive picture for policy makers.

The index applied in this work can be further developed and applied for different purposes. For example, it is based on a simple definition of the reference groups for the cross-sectional component, based on a cross-classification by geographical area and some socio-demographic characteristics of the individuals. However, other more complex strategies to define homogeneous reference groups could be considered as, for example, clustering algorithms allowing the use of both quantitative and qualitative variables.

In addition, the individual scores obtained from the index can be used to study the causal relationship between economic insecurity and other phenomena. Finally, as data become available, it will be possible to use the proposed index to compare perceptions of economic insecurity during and after the pandemic.

Appendix A

Proofs

Property (Gain-loss Monotonicity). For all $t \in \mathbb{N}$, for all $p, q \in \mathbb{R}_{++}, (p > q$ to guarantee that $p - q \in \mathbb{R}_{++}),\ I^t(p+q, p1_t) > I^t(p, p1_t) > I^t(p-q, p1_t)$

$$\ln\left(\frac{x_{-t}}{x_{-(t-1)}}\right)\begin{cases} >0 & \text{if } \frac{x_{-t}}{x_{-(t-1)}}>1 \\ =0 & \text{if } \frac{x_{-t}}{x_{-(t-1)}}=1 \\ <0 & \text{if } 0<\frac{x_{-t}}{x_{-(t-1)}}<1 \end{cases}$$

Proof. Focusing on the LI_R^t component:

Considering that $l_0, g_0 \in \mathbb{R}_{++}$ and $\delta \in \left(0, \min\left\{\frac{l_0}{g_0}; \frac{g_0}{l_0}\right\}\right)$, $l_0\delta^{t-1}$ and $g_0\delta^{t-1}$ are positive $\forall l_0, g_0 \in \mathbb{R}_{++}$. Hence:

$$\begin{aligned} LI_R^t\left(p+q, p1_t\right) &> 0. \\ LI_R^t\left(p, p1_t\right) &= 0. \\ LI_R^t\left(p-q, p1_t\right) &< 0. \end{aligned}$$

Therefore LI_R^t satisfies the property. It follows that, ceteris paribus, the property is also satisfied by CI^t.

Property (Proximity Monotonicity). For all $t \in \mathbb{N}$, for all $p, q \in \mathbb{R}_{++}$, ($p > q$ to guarantee that $p-q \in \mathbb{R}_{++}$), $I^{t+2}\left(p,p,p+q,p1_t\right) > I^{t+2}\left(p,p+q,p,p1_t\right) > I^{t+2}\left(p,p,p,p1_t\right) > I^{t+2}\left(p,p-q,p,p1_t\right) > I^{t+2}\left(p,p,p-q,p1_t\right)$.

Proof. Focusing on the longitudinal component, if we replace LI_R^{t+2} (Equation 1) in the Proximity Monotonicity general condition, we obtain:

$$l_0\delta^{t-1}\ln\left(\tfrac{p+q}{p}\right) + g_0\delta^t\ln\left(\tfrac{p}{p+q}\right) > l_0\delta^t\ln\left(\tfrac{p+q}{p}\right) + g_0\delta^{t+1}\ln\left(\tfrac{p}{p+q}\right) > 0 > l_0\delta^{t+1}\ln\left(\tfrac{p}{p-q}\right) + g_0\delta^t\ln\left(\tfrac{p-q}{p}\right) > l_0\delta^t\ln\left(\tfrac{p}{p-q}\right) + g_0\delta^{t-1}\ln\left(\tfrac{p-q}{p}\right).$$

By the properties of the logarithm:

$$\ln\left(\tfrac{p+q}{p}\right)\left[l_0\delta^{t-1} - g_0\delta^t\right] > \ln\left(\tfrac{p+q}{p}\right)\left[l_0\delta^t - g_0\delta^{t+1}\right] > 0 > \ln\left(\tfrac{p-q}{p}\right)\left[g_0\delta^t - l_0\delta^{t+1}\right] > \ln\left(\tfrac{p-q}{p}\right)\left[g_0\delta^{t-1} - l_0\delta^t\right].$$

The above inequalities may be also written as:

$$\ln\left(\tfrac{p+q}{p}\right)\delta^{t-1}\left[l_0 - g_0\delta\right] > \ln\left(\tfrac{p+q}{p}\right)\delta^t\left[l_0 - g_0\delta\right] > 0 > \ln\left(\tfrac{p-q}{p}\right)\delta^t\left[g_0 - l_0\delta\right] > \ln\left(\tfrac{p-q}{p}\right)\delta^{t-1}\left[g_0 - l_0\delta\right].$$

This succession of inequalities are satisfied if $l_0, g_0 \in \mathbb{R}_{++}$, $t \in \mathbb{N}$ and $\delta \in \left(0, \min\left\{\frac{l_0}{g_0}; \frac{g_0}{l_0}\right\}\right)$, because:

- $[g_0 - l_0\delta]$ is positive for $\delta \in \left(0, \min\left\{\frac{l_0}{g_0}; \frac{g_0}{l_0}\right\}\right)$;
- $[l_0 - g_0\delta]$ is positive for $\delta \in \left(0, \min\left\{\frac{l_0}{g_0}; \frac{g_0}{l_0}\right\}\right)$;
- $\ln\left(\frac{p+q}{p}\right)$ is positive and $\ln\left(\frac{p-q}{p}\right)$ is negative;
- $\left|\delta^{t-1}\right| > \left|\delta^{t}\right|$ if $\delta \in \left(0, \min\left\{\frac{l_0}{g_0}; \frac{g_0}{l_0}\right\}\right)$.

It follows that the property is satisfied by LI_R^t and, ceteris paribus, by CI^t.

Property (Quasilinearity). For all $T \in \mathbb{N} \setminus \{1\}$, there exists a function $F_{++}^T : \mathbb{R}^2 \to \mathbb{R}$, such that for all $x \in \mathbb{R}_{++}^T$, $I^T(x) = I^{T-1}\left(x_{-(T-1)}, \ldots, x_0\right) + F^T\left(x_{-T}, x_{-(T-1)}\right)$.

Proof. Considering the function $F_{++}^T : \mathbb{R}^2 \to \mathbb{R}$:

$$F^T(x,y) = \begin{cases} l_0\delta^{T-1}\ln\left(\frac{x}{y}\right) & \text{if } x \geqslant y \\ g_0\delta^{T-1}\ln\left(\frac{x}{y}\right) & \text{if } x < y \end{cases}$$

The property is satisfied by LI_R^t and, ceteris paribus, by CI^t.

Property (Stationarity). For all $r \in \mathbb{N}_0$, an increasing function $G^r : \mathbb{R} \to \mathbb{R}$ exists, such that for all $t \in \mathbb{N}_0$ and for all $p, p', s \in \mathbb{R}_{++}$, $I^{(t+2+r)}(p, p', s1_{t+1}, s1_r) = G^r\left(I^{t+2}(p, p', s1_{t+1})\right)$.

Proof. Focusing on the longitudinal component, considering the function $G^r : \mathbb{R} \to \mathbb{R}, G^r(y) = \delta^r y$, and replacing LI_R^t, in the general condition of Stationarity, we obtain: $LI_R^{(t+2+r)}(p, p', s1_{t+1}, s1_r) = \delta^r\left(LI_R^{(t+2)}(p, p', s1_{t+1})\right)$.

Considering that $s1_r$ is a vector of constant values, the two streams lead to the same level of insecurity. It follows that the property is satisfied by LI_R^t and, ceteris paribus, by CI^t.

Property (Scale Invariance). For all $T \in \mathbb{N}$, for all $x_i^* \in \mathbb{R}_{++}^{T+N_j}$ and for all $b \in \mathbb{R}_{++}$:

$$I^T(bx_i^*) = I^T(x_i^*)$$

.

Proof. Scaling all values of $x_i^* \in \mathbb{R}_{++}^{T+N_j}$ by a fixed amount $b \in \mathbb{R}_{++}$ does not change the result of the function. This is by definition of relative change. Therefore, this property is satisfied by CI^t.

Appendix B

Table B1 ε values for all European countries from 2014 to 2019

	2014	2015	2016	2017	2018	2019
Austria	0.4183	0.4830	0.4748	0.5971	0.5489	0.5564
Belgium	0.5037	0.5876	0.5012	0.6076	0.5019	0.5591
France	0.6163	0.5869	0.6120	0.6105	0.6416	0.5388
Poland	0.5765	0.5556	0.4531	0.5265	0.4673	0.4915
Denmark	0.4784	0.5726	0.6034	0.5432	0.4774	0.6216
Sweden	0.3917	0.5502	0.4868	0.5827	0.5529	0.5365
Finland	0.6333	0.5719	0.5972	0.6259	0.6148	0.5855
Greece	0.4830	0.5605	0.5672	0.6755	0.4299	0.6053
Spain	0.5470	0.6529	0.5728	0.5514	0.5603	0.5763
Italy	0.6660	0.5533	0.5944	0.6175	0.6236	0.5399

Notes ε is the weight assigned to the longitudinal component, $1 - \varepsilon$ is the weight assigned to the cross-sectional one

Source Own elaboration on EU-SILC longitudinal data

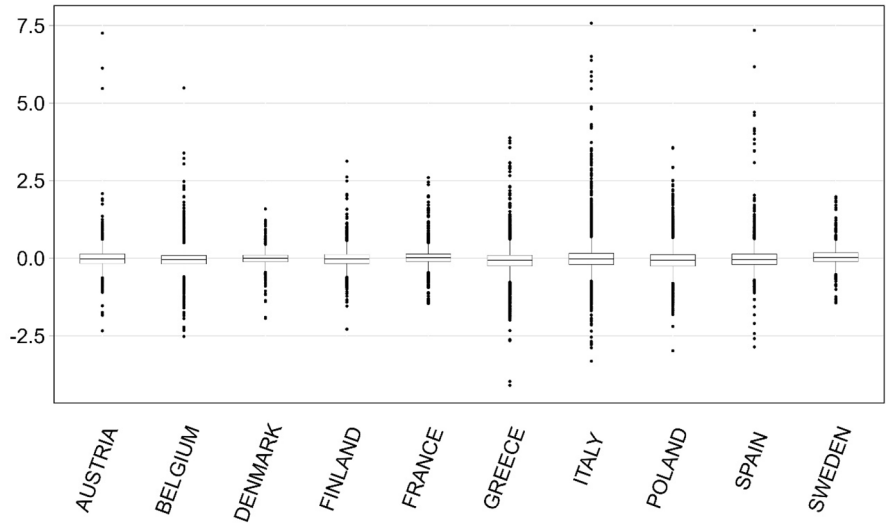

Figure B1 Box plots of CI scores by country (2019). *Source* Own elaboration on EU-SILC longitudinal data

Table B2 Yearly changes of the weighted means of the household equivalized disposable income (2014–2019)

	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019
	yearly change%	yearly change%	yearly change%	yearly change%	yearly change%
Austria	–2.08	7.75	–2.66	–0.71	5.40
Belgium	–0.15	–2.95	2.81	5.04	5.15
France	5.85	–0.85	–1.38	0.69	–5.19
Poland	3.63	1.52	5.72	11.58	2.30
Denmark	3.97	8.00	–7.55	–0.63	–0.33
Sweden	–3.33	3.15	–3.85	–5.87	1.65
Finland	0.40	0.38	2.23	–1.01	4.19
Greece	2.49	3.97	4.11	–3.72	8.39
Spain	6.07	0.29	1.97	2.79	–1.50
Italy	–0.68	–0.29	–0.71	3.08	4.06

Source Own elaboration on EU-SILC longitudinal data

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