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FACTOR DECOMPOSITION OF CROSS-COUNTRY INCOME INEQUALITY WITH INTERACTION EFFECTS

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Factor decomposition of cross-country income inequality with interaction effects

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Abstract

In this paper we propose a decomposition of the Theil measures of per capita income inequality which accounts for interaction effects between its multiplicative factors. Our theoretical findings, supported by an empirical application referring to EU-25 countries, suggest that neglecting these effects may strongly bias the relative importance of some factors, with consequent misleading policy implications.

Keywords: Inequality, Decomposition, Interaction Effects

JEL classification: C10; D63; O10

1. Introduction

Per capita income may be expressed as the product of many factors. The basic decomposition is into the two classical determinants of the *wealth of nations*: the share of population employed, and labour productivity. In turn, each of these can be multiplicatively decomposed into more specific factors.
Irrespective of their number, an interesting question concerns how to measure their contribution to inequality in cross-country (or region) per capita income. For this aim, Duro and Esteban (1998) proposed an additive decomposition based on the *second* Theil inequality measure. This approach was criticised by Cheng and Li (2006) who developed a method, noted by the same Duro and Esteban, in which a residual term emerges and is interpreted as an interaction effect between the components.
In this paper, we propose a new decomposition of the *first* and *second* Theil inequality measures (Theil, 1967; Bourguignon, 1979) of per capita income with interaction components. We show that, for different reasons, this method should be considered preferable to the above-mentioned ones. An application referring to EU-25 countries is provided to corroborate our theoretical findings.

2. Decomposition of per capita GDP inequality with interactions

Let X_i, E_i, P_i (*i=1, …, N*) be country *i* GDP, employment and population, respectively, and *X, E, P* the corresponding total values (i.e., $X = \sum_i X_i$, etc.). Let x_i be country per capita GDP, with weighted mean $\mu(x) = X/P$, and p_i the country share of population on total ($p_i = P_i/P$).
Both x_i and $\mu(x)$ may be expressed as the product of two factors:

$x_i = X_i / P_i = (X_i / E_i) (E_i / P_i) = y_i \; e_i$

$\mu(x) = X / P = (X / E) (E / P) = \mu(y) \mu(e)$

where y_i and e_i are country labour productivity and employment rate on total population, respectively, and $\mu(y)$ and $\mu(e)$ their weighted means.

The corresponding population–weighted Theil inequality index (so-called second measure) may be decomposed into two additive components, as follows:

$$T(x, p) = \sum_i p_i \ln \frac{\mu(x)}{x_i} = \sum_i p_i \ln \frac{\mu(y)\mu(e)}{y_i e_i} = \sum_i p_i \ln \frac{\mu(y)}{y_i} + \sum_i p_i \ln \frac{\mu(e)}{e_i} =$$

$$= T(\mathrm{y}, p) + T(\mathrm{e}, p) \qquad (1)$$

This decomposition is provided, via a more complex procedure, by Duro and Esteban (1998) who show that each additive term represents the contribution to GDP per capita inequality of each initial multiplicative factor.
As noted by Cheng and Li (2006), this approach does not consider explicitly the interaction effect deriving from the correlation between the components of per capita GDP. In order to account for this effect, Cheng and Li (2006) proposed another method (reported by Duro and Esteban in a footnote) which they developed using an unweighted version of the Theil inequality index:

$$T(x) = \frac{1}{N} \sum_i \ln \frac{\mu'(\mathrm{x})}{\mathrm{x_i}} = \frac{1}{N} \sum_i \ln \frac{\mu'(\mathrm{y})\mu'(\mathrm{e})}{\mathrm{y_i e_i}} \frac{\mu'(\mathrm{x})}{\mu'(\mathrm{y})\mu'(\mathrm{e})} = T(\mathrm{y}) + T(\mathrm{e}) + \ln \frac{\mu'(\mathrm{x})}{\mu'(\mathrm{y})\mu'(\mathrm{e})} \qquad (2)$$

where $\mu'(\mathrm{x})$, $\mu'(\mathrm{y})$ and $\mu'(\mathrm{e})$ are the un-weighted means of x_i, y_i and e_i, respectively. The residual $\ln \frac{\mu'(\mathrm{x})}{\mu'(\mathrm{y})\mu'(\mathrm{e})}$ is interpreted by Cheng and Li as an interaction effect which reflects the correlation between *y* and *e*.
However, it should be noted that this residual term only survives if the unweighted Theil measure and means are used. This choice is at least debatable, since equal importance in determining inequality is assigned to

each country (or region) per capita income, irrespective of their economic or demographic size. When weighted means are used, since $\mu(x)=\mu(y)\cdot\mu(e)$, the residual term of Cheng and Li becomes zero.

To properly consider the interaction effect between components, we must go back to decomposition (1), where the second component, $T(e, p)$, is a proper Theil index (second measure) and can correctly be interpreted as the share of inter-country per capita income inequality attributable to the employment factor. However, the first component, $T(y, p)$, is not a proper Theil index, since the weighting factor here should be the country employment share ($h_i = E_i/E$), rather than the population share (p_i). Thus, the proper Theil index for the first component is:

$$T(y,h) = \sum_i h_i \ln \frac{\mu(y)}{y_i}$$

Consequently, decomposition (1) becomes:

$$T(x,p) = \sum_i h_i \ln\frac{\mu(y)}{y_i} + \sum_i p_i \ln\frac{\mu(e)}{e_i} + \sum_i (p_i - h_i) \ln \frac{\mu(y)}{y_i} \qquad (3)$$

The third addend (residual term) is easily rearranged as follows:

$$\sum_i (p_i - h_i) \ln\frac{\mu(y)}{y_i} = \sum_i (h_i - p_i) \ln\frac{y_i}{\mu(y)} = \sum_i \frac{P_i}{E}\left(\frac{E_i}{P_i} - \frac{E}{P}\right)\left[\ln y_i - \ln \mu_g(y) + \ln\frac{\mu_g(y)}{\mu(y)}\right] =$$
$$= \frac{1}{\mu(e)}\sum_i p_i\,[e_i - \mu(e)]\,[\ln y_i - \ln\mu_g(y)] \qquad (4)$$

where μ_g is the geometric mean of the variable.

Apart from the scalar $1/\mu(e)$, this residual term is the co-variance, weighted by p_i, between e_i and $\ln y_i$, and may this be interpreted as an interaction effect, depending on the correlations between these two variables.

Denoting this interaction effect by $\Delta_{y,e}$, equation (3) becomes:

$$T(x,p) = T(y,h) + T(e,p) + \Delta_{y,e}. \qquad (5)$$

Since $T(y, p) = T(y, h) + \Delta_{y,e}$, in equation (1) the interaction factor is inside $T(y, p)$, which therefore cannot be interpreted as the share of inequality attributable only to the productivity factor of per capita GDP. This clarifies a point considered puzzling by Cheng and Li, i.e, why one factor of (1) could contribute negatively to inequality. The two factors may indeed be of opposite sign when the contribution of one of them is partially (or totally) offset by the other one. For the sake of clarity, let us suppose that the countries examined have the same per capita GDP, so that the Theil index is zero, but both labour productivities and employment rates show some variability. Using decomposition (1), we would necessarily obtain components of opposite signs (and strength). However, the true reason why a component may be negative lies in the fact that it includes the interaction effect, which may be negative (if the correlation between the interacting variables is negative) and strong enough to affect the sign of the improperly measured component.

Using the same approach, we can of course decompose the income-weighted Theil index (first measure) as follows:

$$T(x,q) = \sum_i q_i \ln\frac{x_i}{\mu(x)} = \sum_i q_i \ln\frac{y_i}{\mu(y)} + \sum_i q_i \ln\frac{e_i}{\mu(e)} = T(y,q) + T(e,q) \qquad (6)$$

Now the second component, $T(e, q)$, is not a proper Theil index, in which the weighting factor should be h_i:

$$T(e, h) = \sum_i h_i \ln \frac{e_i}{\mu(e)}$$

In this case decomposition (6) becomes:

$$T(x, q) = \sum_i q_i \ln \frac{y_i}{\mu(y)} + \sum_i h_i \ln \frac{e_i}{\mu(e)} + \sum_i (q_i - h_i) \ln \frac{e_i}{\mu(e)} \tag{7}$$

The residual term is now:

$$\sum_i (q_i - h_i) \ln \frac{e_i}{\mu(e)} = \frac{1}{\mu(y)} \sum_i h_i [y_i - \mu(y)] [\ln e_i - \mu_g(e)] \tag{8}$$

Now the residual term measures the interaction effect deriving from the correlation between y_i and $\ln e_i$. Denoting this interaction effect as $\Delta'_{y,e}$, equation (7) becomes:

$$T(x, q) = T(\mathrm{y}, q) + T(\mathrm{e}, h) + \Delta'_{y,e} \tag{9}$$

Again, since $T(\mathrm{e}, q) = T(\mathrm{e}, h) + \Delta'_{\mathrm{y,e}}$, in equation (6) the interaction component is inside T(e, q), which therefore cannot be interpreted as the share of inequality attributable only to employment differentials.

The proposed approach can obviously be used for more complex decompositions of per capita GDP, for example into four factors:

$$x_i = X_i / P_i = (X_i / L_i)(L_i / E_i)(E_i / Pl_i)(Pl_i / P_i) = y'_i \; c_i \; e'_i \; d_i$$

where the new notations L_i and Pl_i are country internal employment and working-age population, respectively. The corresponding weighted mean $\mu(x)$ is then:

$$\mu = X / P = (X / L)(L / E)(E / Pl)(Pl / P) = \mu(y')\, \mu(\mathrm{c})\, \mu(e')\, \mu(d)$$

where $L = \sum_i \mathrm{L_i}$, and $Pl = \sum_i \mathrm{Pl_i}$.

This longer decomposition allows us: (i) to measure productivity and employment rate more correctly by means of two different measures of employment[1]; (ii) to measure the employment rate on the working age population; and (iii) to take into account the age structure of the population.
Going back to equation (5), the decomposition of $T(x, p)$ into four components is easily obtained by applying the decomposition in two components to both $T(y, h)$ and T(e, p):

$$T(y, h) = \sum_i h_i \ln \frac{\mu(y)}{y_i} = \sum_i l_i \ln \frac{\mu(y')}{y'_i} + \sum_i h_i \ln \frac{\mu(c)}{c_i} + \sum_i (h_i - l_i) \ln \frac{\mu(y')}{y'_i} =$$

$$= T(\mathrm{y'}, l) + T(\mathrm{c}, h) + \Delta_{y',c} \tag{10}$$

where $l_i = L_i / L$, and:

[1] *Internal* employment ($\mathrm{L_i}$) is used for productivity, since GDP is measured on "internal bases"; *residential* employment ($\mathrm{E_i}$) is used for the employment rate, since working age population is, of course, resident population. The two measures may differ due to commuting flows, presence of foreign non-resident workers, and statistical errors.

$$T(e,p) = \sum_i p_i \ln \frac{\mu(e)}{e_i} = \sum_i w_i \ln \frac{\mu(e')}{e'_i} + \sum_i p_i \ln \frac{\mu(d)}{d_i} + \sum_i (p_i - w_i) \ln \frac{\mu(e')}{e'_i}$$

$$= T(\text{e}', w) + T(\text{d}, p) + \Delta_{e',d} ; \qquad (11)$$

where $w_i = Pl_i / Pl$.

Lastly, the decomposition of $T(x, p)$ (second measure) into four components is:

$$T(x, p) = T(y', l) + T(c, h) + T(e', w) + T(d, p) + \Delta_{y,e} + \Delta_{y',c} + \Delta_{e',d} \qquad (12)$$

Correspondingly, moving from equation (9) and decomposing the two components $T(\text{y}, q)$, $T(\text{e}, q)$, we obtain the following Theil inequality (first measure) index, broken down into four components:

$$T(x, q) = T(y', q) + T(c, l) + T(e', h) + T(d, w) + \Delta'_{y,e} + \Delta'_{y',c} + \Delta'_{e',d} \qquad (13)$$

3. Decomposition of per capita GDP inequality in the EU-25 countries

We employ the above approach to decompose into four components cross-country per capita GDP (market prices, euro PPPs) of the 25 EU members before the 2008 enlargement. Data are from Eurostat and refer to 2005. We aim here at providing one example of the differences obtained by: (i) using or not using the interaction terms; (ii) using the two Theil measures, i.e, weighting with population *versus* income shares.
Table 1 lists results for the first Theil measure, with and without interaction terms. Apart from the productivity component, which obviously remains unchanged, the data reveal that a great deal of the impact assigned to the L/E factor (9.2%) is due to the interaction effect between this component and productivity (6.9%); similarly, the true role of the employment rate (17.1%) is less than half that emerging without interaction terms (36.6%). Interestingly, the properly measured demographic component contributes around 1% to total inequality, whereas in the absence of interactions it seemed to act as a factor reducing inequality (-15.8%). However, this negative sign is the effect of the negative correlation between ln *e'* and *d*, as highlighted by the sign of their interaction term.

Table 1
Decomposition of per capita GDP in 2005 without and with interactions (Theil 1, income weighted)

Components		*%*	*Components*		*%*
T(y',q)	0.01872	69.924	T(y',l)	0.01872	69.924
T(c,q)	0.00248	9.246	T(c,h)	0.00063	2.342
			$\Delta'_{y',c}$	0.00185	6.904
T(e',q)	0.00980	36.586	T(e',w)	0.00459	17.148
T(d,q)	-0.00422	-15.757	T(d,p)	0.00030	1.132
			$\Delta'_{y,e}$	0.00136	5.080
			$\Delta'_{e',d}$	-0.00068	-2.530
T(x,q)	*0.02677*	*100*	*T(x,p)*	*0.02677*	*100*

Similar comments may be provided with reference to the outcomes obtained using the second Theil measure (Table 2). The comparison between the population-weighted and properly weighted decompositions reveals, in the first case, an overestimation of the role of productivity differences (85% instead of 68%), strongly biased by the interaction factors between *y* and *e* and *y'* and *c*. Conversely, the importance of employment rates is underestimated if the interaction between *e'* and *d* (negative) is not considered.

Table 2
Decomposition of per capita GDP in 2005 without and with interactions (Theil 2, population weighted)

Components		*%*	*Components*		*%*
T(y',p)	0.02640	84.972	T(y',l)	0.02109	67.873
T(c,p)	0.00044	1.422	T(c,h)	0.00061	1.973
			$\Delta_{y,e}$	0.00296	9.529
			$\Delta_{y',c}$	0.00218	7.018
T(e',p)	0.00393	12.638	T(e',w)	0.00463	14.904
			$\Delta_{e',d}$	-0.00070	-2.266
T(d,p)	0.00030	0.969	T(d,p)	0.00030	0.969
T(x,p)	*0.03107*	*100*	*T(x,p)*	*0.03107*	*100*

The comparison between the left panels of the two tables shows that, if the interaction terms are not taken into account, the decomposition may lead to very different outcomes in identifying the components of inequality, depending on the choice of the first or second Theil measure. However, these huge differences tend to shrink greatly if the interaction terms are accounted for (right panels).

4. Conclusions

This paper proposes a new decomposition of the Theil (first and second) measures of per capita income inequality. With respect to previous approaches, our method allows us to distinguish the role of the multiplicative components of per capita income from their interaction effects. Correctly isolating these effects also allows us to address otherwise unresolved points, e.g., the negative sign of one or more components when interactions are not considered. Our empirical application to 25 EU countries shows that the explicit consideration of interaction terms drastically reduces the great differences obtained using the first or second Theil measure. Conversely, if not explicitly considered, interaction effects may strongly bias the relative importance of the multiplicative factors of per capita GDP, with consequent misleading policy implications.

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