Intergenerational Equity and Transitional Inequality Measurement: Techniques and Empirics

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Abstract

This paper discusses the measurement of both the intergenerational equity and the transitional inequality where the latter is a measure of distance to a transitional goal. The issue is relevant especially for ecological sustainability which is the main aspect treated, and can be extended to a set of transitional goals as the Agenda 2030. The empirics show that we had non-sustainable intergenerational equity and that no transition has been performed; therefore, it is hard to believe that there will be no necessity for inequality to reach the intergenerational equity.

Keywords: Intergenerational equity; Transitional inequality; Intergenerational equity indicators; Sustainable development indicators

1. Introduction

1.1 Aim

This paper discusses the meaning of intergenerational equity, transitional inequality and under which conditions such a transition can be considered fair. Measurement techniques of these aspects are provided, and the empirics follow at the end of each of the next sections.

1.2 Progress and right

To deal with the intergenerational equity, we need a principle according to which judging a behaviour or result as fair or unfair. The quality of the principle defines the value of the judgment. The "Principle of Self-determination of Progress" is adopted:

"Each society in each time has the right to pursue its progress to the extent that, by doing so, it does not affect, in the space and in the time, the other generations right to do the same."

Many contributes are aligned to this principle. Of relevance are: The famous The Brundtland Commission (United Nations General Assembly 1987), the definition of sustainable development and the United nation principles 11 and 23 of (United Nations 1972) and the responsibility principle of Jonas (1979). The difference depends upon the adopted definition and interpretation of progress. Let me define progress[1] as a set of states where these states are goals. Hence, each society has the right to pursue its own goal to the extent that its actions do not compromise the capacity of the future generations or of

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[1] From Nathan Rotenstreich (1971), p.1:"[…] In common usage, the term "progress" signifies an improvement or an advance in a desirable direction. As the ruling idea or as a doctrine concerning the character of history, progress implies a cumulative advance, […]". Here, I will adopt a static definition of progress as an idea of the world we would like, or we retain equitable, to reach.

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the other countries to do the same. Let me define transition as a series of consecutive states over time. A transition that reduces the distance to the goals is a development; if the distance increases is a regress and if it is the same is stable. Any non-stabile transition generates an inequality between the generations in terms of distance to the goal, but it still may be fair if protects the rights of other societies. Hence, inequality in terms of progress may be justified by equality in terms of rights.

The goals change as the societies and the contexts change, and a goal today has a certain probability to not be included in the progress set for a future society. Indeed, there are different and continuously evolving ideas of progress (Turgot 1750; Nisbet 1980; Iggers 1958; Mommsen 1951; Wagner 2010; Rotenstreich 1971). The modern agenda 2030 (United Nations 2015) is only one of them and there is no reason to believe that in the future will not change. The volatility of the definition of progresses impedes to determine how our behaviour today may compromise the future generation's right to self-determine. [2] In such uncertainty, the most rational behaviour is to select those dimensions that are more likely to be necessary for future development.

The principle adopted can be accepted only as a negative sense of the Golden Rule: Do not do what you would not like to receive, and more strictly, concerning not our intention of development but the other's intention: *do not do to others what others would not like to receive.* Hence, to impose our progress as the progress of every country and generation is unfair. If it is impossible to define the future idea of progress, then the temptation is to approximate it with our, but this is not necessarily fair, it is dictated only by our lack of knowledge.

The ideal situation would be to find dimensions that are a necessary condition (i.e. very likely) for all kind of progress. Few dimensions can be defined as such if we look to the different cultures over the human stories. However, an obvious condition for any human progress is life and human life, in other words, the ecological sustainability. Accordingly, this will be the focus of this paper.

The respect of the others' progress impedes to some to take advantage of someone else. An example can be found in the work by the Nobel prize winner Nordhaus (Nordhaus 2018; Groth 2018). He addressed the climate change by analysing its costs and benefits, estimating which temperature change would be optimal. Anyway, even if the sum of the benefits in the optimum is greater, it is not necessarily fair since it may advantage some by damaging someone else. Without compensation, it is a reduction of the rights of some for the advantage of others. Hence, the intertemporal wellbeing maximization may be a possible goal but not a right. In particular, I deny the approach used by Beckerman (1994) because, if he is right when he says that it is impossible to interpret the word "needs" in the Brundtland report (World commission on environment and development 1987), since they change as the societies change, and if he is right saying that sustainability must be treated as a technical requirement, then, in my opinion, he is wrong when he treats wellbeing maximization as a solution. Indeed, since it is subjective, it is affected by the same criticisms he brings to the needs: Economists often confuse the advantages in the

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[2] The transitions to a given goal are made by stages that, as such, could be goals as well, let me define them transitional goals generating an evolution of the way through which the progress can be defined and reached (Zylicz 2010).

utilization of utility with the fact that utility is subjective, unstable and not necessarily a consistent concept.

Clear examples of this limit are the modern progress frameworks (Bova 2019a; Hall, Giovannini, Morrone and Ranuzzi 2010) that juxtapose the words equitable and sustainable to wellbeing to define the modalities according to which wellbeing can be pursued. The wellbeing approach suffers at least of three critic points. The first is that, since the wellbeing is subjective (Maggino 2015), its aggregation in a society is as weak as the heterogeneity of the subjects' preference is large. Hence, in heterogeneous societies, the simultaneous maximization of different preferences may lead to clear unfair situations. The second is that, since it is subjective, few aspects resist over time or we have no tools to define which of those aspects will resist. Hence, its measurement requires constant updates and its validity and comparability is encompassed in the short term and can be done only ex-post and, therefore, without a clear long term predictive and planning ability. Third, if the wellbeing is the goal, then the weak sustainability (i.e. capitals sustainability) cannot be rejected. What we sustain is what sustains the wellbeing. However, in order to allow such a substitution, we need to evaluate these capitals in terms of marginal utility and, by doing so, we apply parameters that depend on the subjective value (i.e. the demand in the market) and the consequent measure can easily become contradictory (see Pillarisetti 2005).

A rational way to face the uncertainty ex-ante in terms of equity can then rely on approaches as the veil of ignorance of Rawls (1971): Without knowing the ambitions (progress) and capacity of a generation, then the best thing to do is to guarantee equality among them. The best thing to do becomes the right thing to do, generating a bridge among liberalism and equalitarianism. However, since we cannot transfer resources across generations to compensate more or less capable or lucky societies, we can only guarantee equality in terms of opportunities.

1.3 To statistics

Two aspects can finally be highlighted and studied: The right to have equality in terms of capacity to pursue the progress, defined from now on as Static intergenerational equality, and the duty to respect the others' right, defined from now on as dynamic intergenerational equality. While the first is a static condition (the same level of natural capital), the latter is dynamic since it is a reduction of natural capital consumption according to the distance to its regeneration capacity. Hence, the dynamic equality holds if the generations have fair behaviour and they do contribute to reach a static equality that can be maintained over time. Indeed, if the distance between consumed and regenerated natural capital is not filled, then sooner or later there will not be enough for any progress. Finally, the societies have the right to intergenerational static equality, but the duty satisfaction generates inequality. Hence, these aspects need to be balanced and the transition cannot be imposed on a unique generation since this would be unrespectful of rights. Hence, the duty has to be spread across the generations in a fair way, that is, proportionally to the distance to the sustainability. In this way, each society has its own progress and a further goal, the sustainability, that is an exogenous goal for the human fairness and survival.

1.4 Structure of the paper
          Section 2 provides techniques and empirics concerning the static inequality, while section 3 concerns the dynamic and the definition of a fair transition. Section 4 instead is dedicated to the inequality in intention as a degree of convergence to the fair rate of transition.

1.5 Premises
          The ecological sustainability in sustainable development is a complex phenomenon and the definition is still debated. Following Bova (2019b), I will prefer, to the extent that is necessary for this work, the definition given by Morelli (2019). Many approaches and indexes are used to measure it. Here, I will use the ecological footprint index following Bova (2019b) in terms of the Earth being necessary to sustain the human consumption. This index will be in the mind of the author while designing tools and selecting examples and, although is neither unique nor necessary the better index(Siche, Agostinho, Ortega and Romeiro 2008), it corresponds to the idea of expressing the consumption in terms of regeneration capacity. In particular, it allows to define a clear goal for the transition and the final equity, a ratio equal to 1: the number of necessary earths is equal to the planet that we have. Finally, since the generations lay on a continuous and different generations' coexistence, I will reduce them, for analytical purposes, to a year: Each year footprint is treated as a generation.

2. Static Inequality: Intergenerational Equity

          This section introduces an indicator to evaluate the static intergenerational equality, where intergenerational static inequality is the inequality measured on the level of consumption over the regeneration of the natural capital approached through the ecological footprint index.

2.1 Equivalent number of equals Index (Q)
2.1.1 Definition
          The statistical tools follow "a measure of intergenerational inequality: Introduction" of Bova (2019b) quoted below.
"Let me take a generic function (W [3]) that respects the Dalton principles of (Dalton 1920) whenever b is different from zero and 1. Let me take into account a vector of n elements $(x_1, x_2, \ldots x_i, \ldots, x_n)$ composed by non-negative and at least one positive values.
$$W = \sum x_i^b \qquad (1)$$
This function can be a wellbeing function [...] representing the sum of utilities, or other measures as the Herfindahl index, for b=2. Without loss of generality, let me observe that a given value of W can be obtained through equal elements, let say Q equals, then the W can be written as

$$W = Q \left(\frac{\sum x_i}{Q}\right)^b = Q^{1-b}(\sum x_i)^b \rightarrow Q = \left(\frac{W}{(\sum x_i)^b}\right)^{\frac{1}{1-b}} \qquad (2)$$

[Properties] It is also trivial to show that, given a value HI=g; 1) There is only one vector

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[3] In the original version it was labelled GI.

of Q equals and n-Q zeros such that W=g 2). Such a vector is the vector composed by the lowest number of non-zero elements, 3)There is not a maximum number of positive elements such that HI=g for min(HI)<g<max(HI). Hence, $1 \leq Q \leq n$ and Q=n if and only if the vector is made only by equal elements.

Q is an index of horizontal equality that indicates the "*Equivalent number of equals generating the same wellbeing (…)*"[4]. As such, it sounds close to the Atkinson index (Atkinson 1970) that gives the equivalent income that, if equally spread, would give the same wellbeing. These measures can complete each other the information provided.". (Bova 2019b).

2.1.2 Properties and overlapping

This index has the properties of additivity, anonymity, decomposability (for b=2), mean independence or homogeneity of degree zero and it does respect the Dalton principles. In Bova (2019b) there is a further index, the overlapping index (O), given by the ratio Q/n where n is the number of units. It expresses Q as a share of the Maximum Q that is the number of elements of the distribution vector. It is easy to see that it respects population independence. Q and O do not respect the perfect ranking, indeed, since the intention is to describe the distributions according to their equivalent number of equals, and given the properties highlighted above, the perfect ranking is absent by definition. I propose here a further adjustment: The rescaled overlapping index. Since Q is always between 1 and n, the following formula is an index encompassed between 0 and 1.

$$Q_{0-1} = \frac{Q-1}{n-1} \tag{3}$$

2.2 Selecting the inequality aversion (b)

To treat generations with equity means to treat them ex-ante equally and then differentiate according to their characteristics. The wellbeing function W is appropriate: Every generation has the same function affected only by a parameter "b" defined ex-ante. "b" is generally labelled as inequality aversion and both Q and the Atkinson index depend on it. Since the inequality aversion is subjective, it should be estimated but it may differ from individual to individual. Moreover, in our analysis, treating generations as individuals is not necessary nor convenient, indeed, it is impossible to estimate it and the inequality aversion does not necessarily correspond to a fairness criterion. If we move from the principle of progress self-determination, the parameter's end is to evaluate the gravity of the distances from the perfect equality. If the principle of self-determination of progress claims that each society should receive and give a sustainable world, then it should penalize those who are not respecting it according to the extent of their fault.

The solution applied by Bova (2019b) was to use b=2 that, instead of a sum of utilities (that holds for h b<1), becomes an inequality index as well, the Herfindahl index (i.e. the sum of squared values). Such a parameter reduces relatively the contribute of these generations which are sustainable (ecological footprint<1) and increase that of those that are not (ecological footprint >1). Moreover, the double face of the function as wellbeing or inequality according to the parameter selected opens two opportunities: The first is that we can analyse the function W as a wellbeing function (when useful), while we can use

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[4] With the proper adjustments provided later it can be enlarged to all b for the wellbeing function.

b=2 to assess immediately the inequality, taking into account the size of the phenomenon since W it is not rescaled. Moreover, such a b allows easy interpretability (see appendix) that, at the very end, is necessary to interpret a result and behave accordingly. Hence, since now, I will apply b=2.

2.3 Empirics I
2.3.1 Parameters definition

The author used b=2 and considered the years 1961-2016. All the countries (127) with all the data since 1961 were selected and the world was selected too. The following computations are based on the Ecological footprint index data[5] .
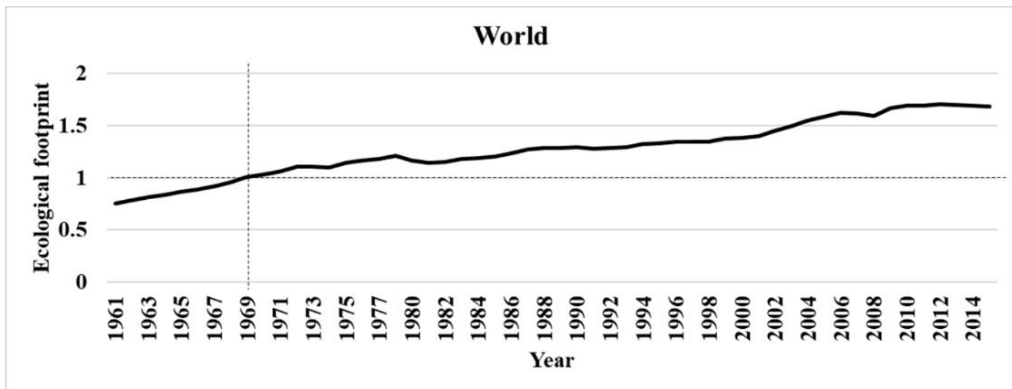
2.3.2 Past world

Figure 1 World ecological footprint (number of earths)

The overlapping rescaled (Q_{0-1}) of intergenerational equity (1961-2016) is 0.956.
This graph shows how, since 1961, the ecological footprint almost constantly increased. Perhaps just the last years' stabile value is a sign of tendency change. The smooth increase leads to a good world intergenerational equity degree of 0.956. However, since the footprint is over the sustainability threshold, the transition should increase such an inequality.

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[5]Global footprint network. Link: Data.footprintnetwork.org. http://data.footprintnetwork.org/?_ga= 2.79047703.2062762760.1580890204-1813421545.1568208246#/compareCountries?type=earth&cn=all&yr=2016

2.3.3 Actual World

Figure 2 Ecological footprint index of countries (2016)

The overlapping rescaled (Q_{0-1}) in 2016 is 0.651.
The values nowadays show a world divided in two blocks: The north (or developed) part of the world with a high impact and the south (developing or underdeveloped) with a low one (except Australia). The inequality in terms of footprint across the countries shows that there is an equivalent of impact concentration in 65,1% of the countries showing how the responsibility for the situation is unbalanced.

2.3.4 Countries

Figure 3 Static intergenerational equity: rescaled overlapping (1961-2016)

The degree of intergenerational equity is quite high for all those countries which did not have a strong development or regress; indeed, China has one of the lowest values. These results, combined with the previous ones, entail that those countries with a too high footprint will generate static inequality by the transition. If their footprint was not stable such inequality is even more severe. Hence, their intergenerational static equity is temporary.

3. Dynamic Inequality: Inequality of Transition

In this section, I will introduce measures and concepts useful for the measurement of dynamic transitional equality. A fair transition, following the reasoning in the introduction, will be such a transition that spreads fairly the cost of transition across generations, where the cost is the renounce to the societies' right. Hence, given a goal of transition, in this case the sustainable ecological footprint, each generation must produce a change proportional to its distance to the goal, this is the transitional goal of a generation. The distance between the change performed and the change expected is a measure of non-equitability of behaviour. Moreover, I will define the groups of equals or supportive (I will use both nouns are interchangeable) as those which respected their duty (the fair transitional goal). Such an approach relies on the distance from a dynamic goal and then on a Boolean evaluation of a performance (fair, unfair) and, as such, cannot take advantage from common measures of inequalities, similarity or groups of equals based on wellbeing or similar approaches (Auerbach and Hassett 1999; Jayadev and Reddy 2011; Kaplow 2000). Hence, a theoretical structure is required.

3.1 Measuring inequality of transition

A fair transition goal can be thought of as a rule "g" that depends on the observed level "x", the goal of the transition (target of the entire transition) "X" and the time of transition. Such a time of transition can be defined as "y" (the final year) minus "t" (the actual year).

$$g(X - x_t, y - t) \tag{4}$$

If such a rule is well defined, the transitional inequality (*ti*) can be defined as the absolute value of the difference between the transition done ($\Delta x_{t \to t+1}$) and the fair transitional goal (*g*)

$$ti = |\Delta x_{t \to t+1} - g(X - x_t, y - t)| \tag{5}$$

Such that in a transition the overall inequality (*TI*) is

$$TI = \sum_{i=t}^{i=t+y} |\Delta x_{i \to i+1} - g(X - x_i, y - i)| \tag{6}$$

3.1.1 Equitable perspective

In a generational perspective, the fair transition is a variation of the footprint level proportional to the distance to the goal. If the observed transition coincides with the fair transition, then such a proportion or fair rate of transition "r" is preserved at an equal level for all the generations such that the cost is fairly spread across them.

$$\Delta x = g = r_{fair}(goal - x) \tag{7}$$

Rearranging the equation with $x_{t+1} - x_t = \Delta x$

B, $\dfrac{x_{t+1} - x_t}{(goal - x_t)} = r_{observed} \tag{8}$

Where "r" in (7) is the fair rate of transition and "r" in (8) is the observed rate of transition. Indeed, while the first depends on g, the transitional goal, the latter depends on the observed behaviour ($x_{t+1} - x_t$) and may be different.

It is important to see how for every r encompassed between 1 and 0, (1 and 0 excluded), the level x tends to the goal of transition over time, but it reaches it only at infinite. This

is consistent with the idea that -all- the generations should carry a share of the cost of transition. It does not matter how little it is. However, let me note that when the distance to the goal of the transition is neglectable, a further transition is not really necessary and it is convenient to come back to the static analysis: The equitable behaviour is evaluated according to the mere distance among the generations' footprint.

3.1.2 Determination of r

To determine "r" we may approach the problem from different perspectives. The first is to define both a threshold distinguishing the dynamic and static equity and a period of transition. In such a case we want to have

$$\sum_{t=1}^{y} r(x_t - goal_t) = (x_t - goal_t) \pm threshold; \quad +if\,((x_t - goal_t) > 0, - otherwise \qquad (9)$$

Given both the threshold and a number of periods y then it is possible to compute r. In the empirics at the end of the section, I will compute the fair rate of transition for a threshold of 0.0001 defining the final year of transition as 2050. Since countries may or may not show a weak tendency to follow a fair transition, r is computed every year. If the transition is respected, then r will be constant, therefore the change of the fair rate of transition becomes a piece of important information as well.

3.1.3 Relative transitional inequality

Since the index of inequality of transition depends strongly on the size of the phenomenon, a linear combination of the same distribution would have different values. To avoid it we can use a relative inequality of transition (RTI) index based on the distance between the observed rates and the fair rates.

$$RTI = \sum_{i=t}^{i=t+y} \left| \frac{x_{t+1}-x_t}{(goal-x_t)} - r \right| \qquad (10)$$

3.1.4 Wellbeing perspective

In the introduction we said that the determinants of the wellbeing are subjective and that they do change over the time. However, it is generally accepted the approximation that it can be expressed as a function of the impact and the technology. The technology represents the capacity of extract, from a given impact, a certain outcome (wellbeing). Hence, if we assume a constant improvement of this technology, then such a technology improvement can contrast the reduction of the impact in such a way that the wellbeing results constant. Such an approximation is still useful since introduces a measure of the perceived cost of the transition.

$$W_{t-1} = f(x_{t-1}) = W_t = f\left(\frac{x_{t-1}}{(1+r)}(1 + i)\right) = f(x_t) \qquad (11)$$

$$\frac{x_{t-1}}{(1+r)}(1 + i) = x_t \; and \; i = r \qquad (12)$$

The previous formula formalizes this concept: A constant reduction given by *(1+r)* (note: It is not the fair rate of transition since it is not based on the distance to the goal) may be contrasted by an increase in the technology *(1+i)* such that the wellbeing remains constant. This information can be useful because, given a yearly footprint reduction, we can know which technology improvement is necessary to maintain the wellbeing, or, vice versa, if we assume a constant technological improvement, then we can determine both the impact

reduction necessary to generate a transition without loss of wellbeing and the years required to perform it:

$$x_1^b = \left(\frac{x_j}{(1+r)^j}(1+i)^j\right)^b = x_j^b = x_y^b = ((1+i)^y)^b \quad \rightarrow \quad y = \frac{\ln(x_1)}{\ln(1+i)} \quad (13)$$

Where $\frac{x_1}{(1+r)^y} = 1$ when we achieve the goal in terms of ecological footprint index.

3.2 Solidarity and defection

We may want to discriminate generations according to their contribution (solidarity) or defection with respect to the goal rate of transition. In such a case, the supportive generations would be those that did their duty or more, vice versa the defectors. The respect of the duty is an observed ratio higher or equal to the fair ratio. Then a supporter would be that which has $(\frac{r_o}{r_f} - 1 \geq 0)$ and a defector a $(\frac{r_o}{r_f} - 1 < 0)$. Therefore, assigning a value 1 for each generation that was supportive, we can compute the average solidarity or solidarity index as follows

$$Solidarity\ Index = \frac{\sum_{i=1}^{i=n} s_i}{n} \quad (14)$$

$$where\ if \left(\frac{r_o}{r_f} \geq 1\right) then\ s_i = 1\ otherwise\ s_i = 0 \quad (15)$$

This measure can be useful to capture a qualitative aspect of the transition; we can measure the number of generations that are behaving equitably and it has the advantage to not depend on any parameter but the number of years of transition and the threshold.

3.3 (Wrong) Concordance Index

A weaker version of the previous index is the wrong concordance index. It simply measures the number of times that the behaviour of a country concords with the required behaviour. In other words, if we expect a reduction (increase) of the impact and the country reduces (increases) the impact, then we have a concordance. This can be reduced to the analysis of the observed rate of transition; if it is positive, then the variation of the impact has the same sign of the variation of the distance to the goal, otherwise it does not. Formally:

$$Wrong\ Concordance\ Index = \frac{\sum_{i=1}^{i=n} c_i}{n} \quad (16)$$

$$Where\ if \left(r_{o,i} \geq 0\right) then\ c_i = 1\ otherwise\ c_i = 0 \quad (17)$$

3.4 Groups of equals

If there is a group of supportive in a row, it is a group of equals, if there is a group of defectors in a row, it is a group of equals as well. A sequence of one group of supportive and one of defectors is a cycle. The cycles will be distinguished by *breaks* while the passage from the supportive to the defectors from a "*pole of equals*" (PoE). Formally, when $s_i = 1$ and $s_{i+1} = 0$ we have a break, if when $s_i = 0$ and $s_{i+1} = 1$ we have a PoE.

The relevance of a break is given by the relative inequality of transition in the cycle. By distinguishing cycles with their RIOT, we can impose a minimum degree of RIOT below which we do not consider a break. This is useful to avoid that slight anomalies may generate the wrong interpretation.

3.5 Empirics II

The empirics are divided into two transitions: The past transition (1998-2016) and the future transition (2017-2050).

3.5.1 Past transition parameters definition

As a transition I will consider the period 1998-2016. The 1998 is a symbolic year since it is immediately after the Tokyo protocol. Since that year, I simulated a transition to 2050 (y=52) in order to compute the fair rate of transition. Since the country may or may not respect it, the fair rate of transition has been computed for each year according to the yearly ecological footprint. The threshold applied is 0.0001. Since when the denominator of the observed rate of transition is too close to zero, the results may be high for a distance to the goal lower than 0.005 (threshold) then the observed rate of transition was arbitrarily reduced to the variation with a positive sign if the variation goes in the direction of the goal or negative otherwise.
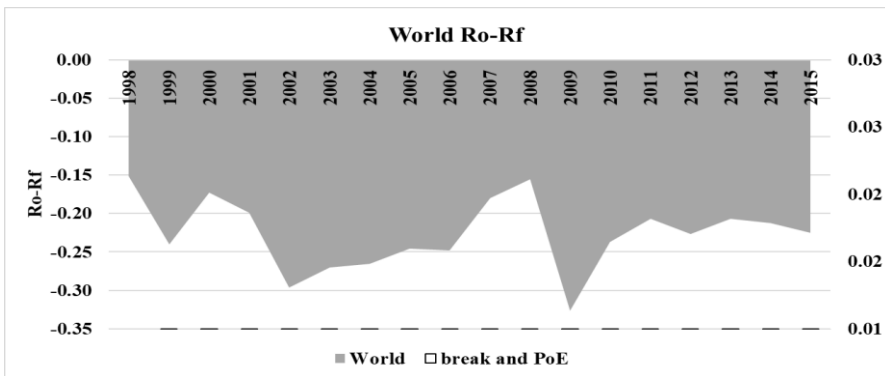
3.5.2 World

Figure 4 Observed and fair rate of transition difference and cycles breaks. World 1998-2016. Note: there are neither breaks nor pole of equals

Table 1 World in 1998-2016

Solidarity	Average distance $r_o - r_f$	Average relative inequality of transition	Average observed rate	Average fair rate	Wrong concordance index
0	-0.23	0.24	-0.04	0.188	0.33

As we could expect from the static analysis, the world results in terms of transition since 1998 are negative and, therefore, there is a unique continuous cycle of defectors with no breaks nor pole of equals. In no year we succeed to achieve the fair rate of transition and only in the 33% of cases we moved toward sustainability (i.e. in the 67% of cases we did not).
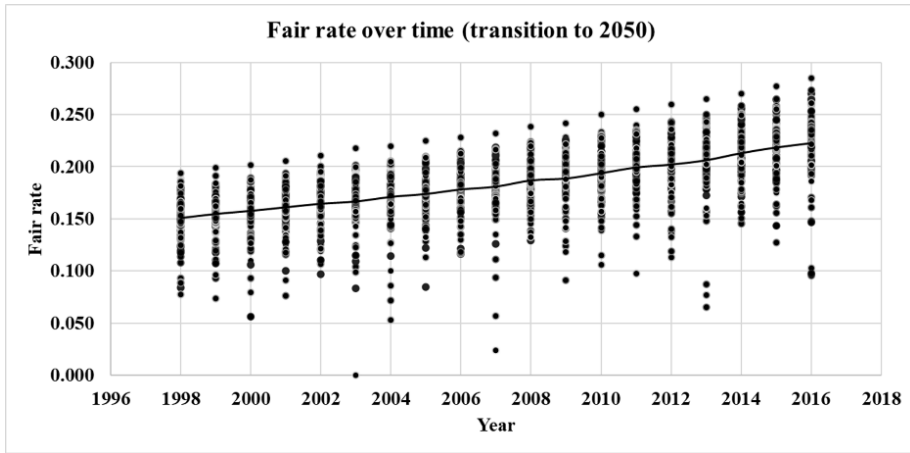
3.5.3 Countries

Figure 5 Fair rate of transition over time in transition to 2050. The dots are the countries rates, the line is their average

Figure 6 Solidarity of transition (1998-2016)

Figure 7 Wrong concordance index (1998-2016)

http://ecsdev.org

Figure 8 Relative average inequality of transition (1998-2016)

Table 2. Countries values (1998-2016)

Average solidarity	Average distance $r_o - r_f$	Average relative inequality of transition	Average observed rate	Average fair rate	Average concordance index
0.13	-0.17	0.29	0.02	0.184	0.52

The result has a double-faced. On one hand, the most impacting countries have a low degree of solidarity, impeding to reduce the overall impact; on the other, many countries with a low impact are -fairly- increasing it. Hence, the results that are positive are almost all due to an increase of impact on those who deserve it. In particular, the developed countries have a quite stable impact and, as such, they do alternate increase and reduction of their impacts. This is the main source of their wrong concordance index. However, by renouncing to follow the transition the fair rate increased, hence, the cost of transition grew as the time to perform the transition declined. The fair rate plot describes a general increase, sign that the cost of transition is generally increasing and as such it is becoming harder to pursue the intergenerational dynamic equity.

3.5.4 Future transition Parameters definition

The parameters used are a) innovation rate of 3%; b) years of end of transition 2050 . Threshold of 0.001.

3.5.5 World

Table 3. World in a fair future transition (2017-2050)

Years of no wellbeing loss transition (i=3%)	Ors (transition 2017 - 2050)	Fair rate (transition 2017- 2050)
17.66	0.986	0.23

If we had an innovation rate of 3% and it was all used to reduce the footprint maintaining the same level of wellbeing, we would need 17 years to achieve sustainability. Such a transition would not be the same across the world and some countries would require a huge effort (54 years) to reach it. Moreover, since we assumed a high innovation rate, and since it is very unlikely that it would be invested all to reduce the impact, the years of

transition will be (many) more. If a fair transition will be followed, then the world intergenerational static inequality would be low but given the unequal concentration of the footprint all over the world, some countries would suffer a high static inequality while some others almost none.
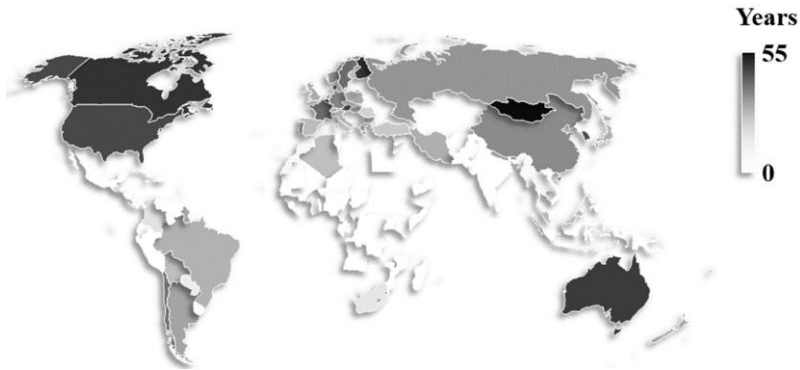
3.5.6 Countries

Figure 9 Number of years required for a non-wellbeing loss transition at a theoretical innovation rate of 3%

Figure 10 Fair rate of transition for country (2017-2050)

Figure 11 Static intergenerational equity across countries in the fair transition 2017-2050

Table 4 Countries in the fair transition 2017-2050

Average number of no wellbeing loss transition years[6] (i=3%)	Average fair rate of transition	Average static intergenerational equity (Ors)
1.77	0.22	0.978

Developed countries present a number of years of non-wellbeing loss transition (with i=3%) in the range of 25-54 years. Such a high innovation rate still leads to a high number of years of transition where these countries would not benefit of any wellbeing increase. Such a high cost explains why developed countries failed to reach their transitional goal and may fail in the future. Moreover, they have a high fair rate of transition and they would generate a high static inequality. On the other side, to do not perform the transition now would only entail a higher cost in all these terms for the next future, hence, the opportunity cost overcomes the gain to wait.

3.5.7 The perverse loop of self-blaming

Since to consume more than what is regenerated cannot be done forever, there is a maximum amount of time to realize the transition. When such a transition is procrastinated, the time to perform it decreases and the effort required to complete it increases. In other words, the lower the solidarity, the higher the fair transitional rate, the harder it becomes to be supportive. In 2016, some countries showed an impact more than four times what can be sustained. It means that, in order to perform a non-wellbeing loss transition, they would need an innovation rate able to generate, at the end, more than four times the wellbeing they now generate from one unit of footprint. The constant attempt to pursue a transition without wellbeing loss would then exasperate the self-blaming perverse loop, and the static intergenerational inequality would be so bitter that the attempt to neglect the problem at all can become more attractive than find a solution.

4. Inequality of Intention

4.1 Introduction

The degree according to which a country is converging to the goal will be labelled intention. A positive intention exists when the distance to the goal decreases, vice versa a negative intention. It is relevant especially when the transitional goal is dynamic, to evaluate the capacity to adapt to a different rate of transition. The logic is close to the inequality of transition.

4.2 Groups of equals

Let me define VV the vector where the i-th element is composed by $VV_i = \left(\frac{x_{t+1}-x_t}{goal-x_t} - r_{fair,t+1}\right) - \left(\frac{x_t-x_{t-1}}{goal-x_{t-1}} - r_{fair,t}\right)$ where the first and the last element of the vector are zeros. A sequence of years with the same sign in terms of convergence shows a period of positive intention (VV<0) or negative intention (VV>0). Hence, when the sign changes, we have a change in intentions. If the sign was negative and becomes positive,

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[6] The low values is given by the fact that some countries are already sustainable and, as such, has a negative number of years.

we have a break, vice versa a pole of equals. The difference with respect to (0) is that here the supportive generations have a negative variation, the defectors a positive and the cycle are cycle of intentions.

4.3 Inequality in intention (VOI)

To distinguish the cycles of intention, we can sum the absolute values of the VV in a cycle and obtain a measure of the volatility of the cycle's intention (*VOI*). Hence, defined "*c*" the index first unit after break, and "*a*" of the last, the inequality in transition can be formalized as follows.

$$VOI = \sum_{i=c}^{i=a} |VV_i| \tag{18}$$

And its average, useful in order to compare different cycles with different length, is

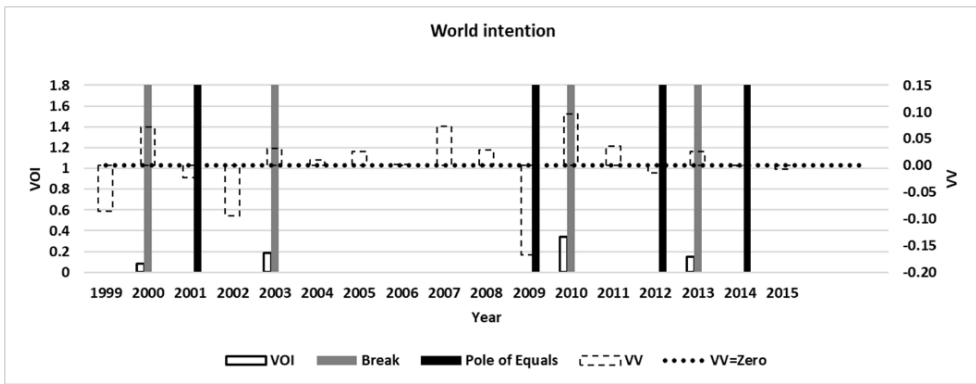$$\overline{VOI} = \frac{\sum_{i=c}^{i=a} |VV_i|}{a-c} \tag{19}$$

Figure 12 World Intention and intention cycles

Since these measures focus on a specific cycle, it shows how intense the cycle is in terms of intentions change. Clearly, the measure can be applied to the overall distribution excluding the first two elements of VV that would be necessarily zero and therefore not informative.

4.4 Solidarity in intention (SiI)

Finally, we can compute the solidarity in intention as the average number of supportive generations, where a supportive generation is one which reduced the distance to the goal, vice versa a defector.

$$\overline{SiI} = \frac{\sum_{i=2}^{i=n-1} \sum si_i}{n-2} \; where \; si_i = \begin{cases} 1 \; if \; VV_i \leq 0 \\ 0 \; if \; VV_i > 0 \end{cases} \tag{20}$$

4.5 Empirics II
4.5.1 World

See figure 12.

Worldwide we have five cycles of intentions. The second (2000-2003) is positive with a reduction of the distance to the fair rate, the third is negative until the 2009 (crisis), the fourth is negative and the last shows no particular intentions. Hence, there is no

convergence to the fair rate.

4.5.2 Countries

Figure 13 Countries average inequality of intention (1998-2016)

Figure 14 Countries solidarity in intention (1998-2016)

Most of the most impacting countries had a low inequality of intention that, with the previous results, show a quite constant trend to ignore the transition. This is even more clear if we look to the solidarity of intention: Since the world is not really coordinated, it is not converging to an inter-countries and intergenerational equity and sustainability.

Conclusion

The adoption of the Principle of Self-determination of Progress claims that each society has the right to pursue its own progress and has the duty to not compromise the right of the other societies, in the space and in the time, to do the same. Defined progress as a set of goals, the first requirement to satisfy this principle across time is the ecological sustainability: Without life is impossible to pursue any other aim. Hence, the principle would entail intergenerational equality: All societies must be equally sustainable.
We can consider two aspects of this equality, a static and a dynamic one. The static inequality is a mere observation of the different degree of natural capital consumption over the natural capital regeneration. The dynamic aspect evaluates the countries not according

to their footprint, but according to its rate of change. If all the generations contributed proportionally to their distance to the sustainability, then a fair rate of change could be defined and its distance from the observed rate of change would be a measure of dynamic inequality. Only when the transition ends we can fully rely on the static analysis.

The static analysis, performed through the Equivalent Number of Equals index, showed how most of the developed countries had a strong static intergenerational equality. However, since they are far from being sustainable, it is temporary and the transition to sustainability is expected to generate a strong future static inequality. Developing countries show lower equality since they are impacting more and more over time and, since their impact is generally lower, their transition could be softer.

The dynamic analysis studied the period 1998-2016 and the eventual transition to sustainability in 2050. The results, analysed through the proposed solidarity index, showed that only developing countries did an effort to the transition -but- it is justified by the fact that their transition often does include an increase in impact since they have the right to. The world as a whole never succeeded to be dynamically equitable. The general failure seems to reach a perverse loop of self-blaming: The more the countries wait for the transition, the higher will be the cost both in terms of rate of transition and in terms of wellbeing. The cost would become so high that, assuming an innovation rate of 3% in terms of capacity to exploit the footprint to generate wellbeing, some countries would need a transition of 54 years to achieve a transition without wellbeing loss. Hence, without a paradigm-break commitment, the loop can do nothing but growth. Finally, looking to the convergence to the fair rate of transition, labelled "Intention", the results are not comfortable, there is no sign it is happening.

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Appendix: Interpretability

The capacity to interpret an index decomposition is necessary for a fair judgment of the results. This appendix shows how a parameter b=2 in the equivalent number of equals allows for a geometrical interpretation of the overall results and its components.

First of all, to set up a b=2 makes the wellbeing function equal to the Herfindahl index of inequality. It is an inequality index in the sense that it respects the Dalton principles, however, it is not rescaled. The fact that is not rescaled allows comparison only among distribution where the sum of the elements is equal. However, it also allows to capture the size of the phenomenon that in the rescaled index is lost.

$$W = \sum x_i^b = \sum x_i^2 = Herfindahl\ Index$$

Let me define a pure distribution where all the elements are equal either to a positive constant or to zero. Such a constant is necessary for the average of the non-zero elements. The number of non-zero elements is labelled *Qpure* . For each b different from zero and 1, Qpure is equal to Q independently from b. Distributions that are not Qpure will be transformed in their equivalent Qpure. Such a transformation result depends on b.

Q is homogeneous of degree 0, therefore, we can manipulate the wellbeing formula in order to make it geometrical. Let me do it by multiply a constant $\frac{2\pi}{n}$ and imposing b=2. The new index obtained (*CI*) is .

$$CI = \frac{2\pi}{n} \sum x_i^2 = W \frac{2\pi}{n}$$

CI is the **sum of the sub areas of circle** where each element of the distribution vector

has its own radius (r), corresponding to xi, its angle, corresponding to $(\frac{2\pi}{n}(i-1), \frac{2\pi}{n}i)$, and its circle part area, equal to $\frac{2\pi}{n}x_i^2$. Furthermore, for b=2, CI is close to the Herfindahl index allowing for comparations.
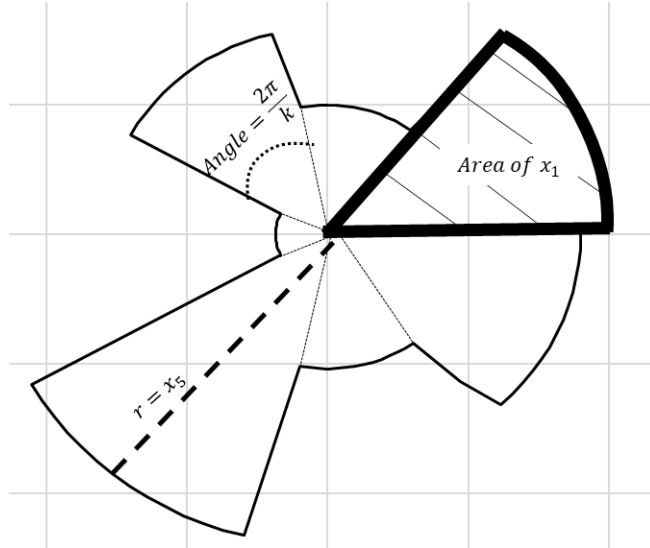

Figure 15 Geometrical description of CI. In the picture n=7

In geometrical terms, transfers from a unit to another may change the overall area CI. In particular, the change increases the overall area if the Dalton principles are respected or if the final distributions have the same CI .

Let me now plot different scenarios (figure below), where each of them is the graphical representation of a different integer value of Q_{pure}. For each Qpure, the radius (xi) is $\frac{\sum x_i}{Q_{pure}}$, and the angle they all together cover is $\frac{2\pi}{n}Q_{pure}$. Consequently, their CI is equal to $\left(\frac{2\pi}{k}Q_{pure}\right)\left(\frac{\sum x_i}{Q_{pure}}\right)^2$. Connecting all the radius at the end of the angles of each sub part of the circle we obtain a spiral. The spiral tracks the radius change when we move from Q= k-1, or angle=0, to Q=1, or angle= 2pigrek. Moreover, each circle partial area (of CI) is a $\frac{Q_{pure}}{n}$ share of the overall circle area computed on r. In turn, it means that we have the following relationship.

$$2\pi r^2 = CI\frac{k}{Q_{pure}} \quad \text{equivalent to} \quad r = \sqrt{\frac{CI\frac{n}{Q_{pure}}}{2\pi}}$$

Hence, we found out three main equations for the geometrical interpretation and two solutions.

$$\begin{cases} CI = \frac{2\pi}{n}\sum x_i^2, \\ r = \frac{\sum x_i}{Q_{pure}}, \\ r = \sqrt{\frac{CI\frac{n}{Q_{pure}}}{2\pi}}, \end{cases}$$

$$solutions: \quad r = \frac{\sum x_i^2}{\sum x_i}$$

$$Q_{pure} = \frac{(\sum x_i)^2}{\sum x_i^2}(=Q)$$

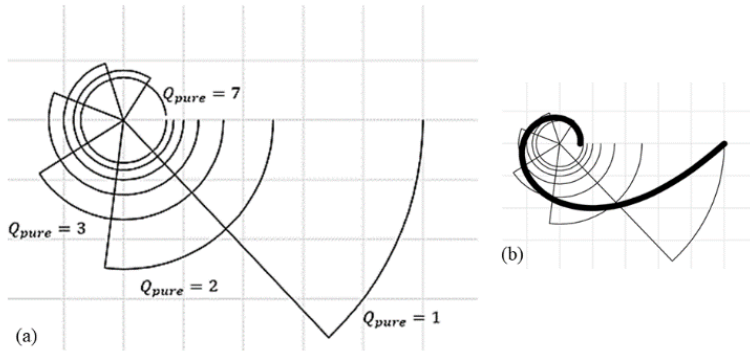*Figure 16 (a): Representation of different levels of Qpure and the circle parts areas; (b) representation of the different level of Qpure and the radius in spiral form*