THE CHALLENGE OF TRACKING EARLY CHILDHOOD DEVELOPMENT: A NEW METHODOLOGICAL APPROACH USING THE MAZZIOTTA-PARETO INDEX

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Abstract. The last two decades have seen remarkable studies in early child development, an interdisciplinary field that involves psychology, economics, and neuroscience. This critical period in child growth exhibits high brain plasticity, and several environmental factors can shape its development by altering gene expression patterns through epigenetic mechanisms, resulting in lifelong impacts. The UN Agenda 2030 includes the Early Child Development Index (ECDI2030) to monitor the Sustainable Development Goal 4.2.1. Although the ECDI2030 has proven to be a useful tool for collecting child development data and addressing public policies, some inherent technical and methodological difficulties need to be addressed, such as, questionnaire design, response to bias in a cross-cultural country, difficulties in handling outliers, and content and duration of the training, among others. Therefore, our goal is to develop a composite index ECDI(i) that incorporates the three dimensions set by the ECDI2030 (i.e., learning, health, and psychological well-being) by using a different methodology, namely the Mazziotta-Pareto Index. Despite the preliminary nature of the results, interesting findings seem to emerge from this study: a positive strong linear correlation between the ECDI(i) and ECDI2030 and a change in ranking is observed.

1. Introduction

Early childhood is defined as the period from prenatal development to the eighth year of life. During this stage, children undergo significant cognitive, social, emotional, and physical changes that shape their future well-being. In the last decade, several studies, such as the Lancet's Series on child development (Grantham-Mcgregor et al. 2007; Walker et al, 2011; Black et al. 2017) demonstrated that the early years represent a crucial window of opportunity, establishing the foundation for lifelong learning, behavior, and health outcomes. It has been highlighted the importance of nurturing care to reach children's full potential, the burden cost of inaction for both individuals and countries, and the role of multi-sector interventions and government leadership. This paper is structured as follows: Section 2

investigates the topic; Section 3 outlines a conceptual framework with the dimensions selected and the methodology adopted and the dataset; Section 4 presents the main results; in the last section, the implications of the research findings are outlined.

1.1 The importance of the Early Child Development.

During early postnatal life, the brain exhibits high plasticity. The developing brain undergoes rapid growth, making it highly responsive to environmental signals which have a profound impact on shaping the neural circuits. The Science of Early Child Development (ECD) shows that epigenetic mechanisms, which alter the activity of genes without changing the order of their DNA sequence, play a key role in mediating the interaction between genes and the environment during early life. This causes a long-lasting change in gene expression underpinning brain functions. (Murgatroyd and Spengler, 2011).

Consequently, child's early interaction with the surrounding environment and responsive caregivers are considered essential for shaping brain architecture and promoting its development. According to Walker et al. (2011), the significant risk factors that hinder children from reaching their full potential are: inadequate cognitive stimulation, stunting, and prenatal maternal nutrition. The research also detects protective factors, such as breastfeeding and maternal education. The consequences of a poor start in life extend beyond the individual, impacting society as a whole. Investments in early childhood development are more cost-effective than remediation and produces greatest returns in human capital (Heckman, 2011). Therefore, understanding and investing in early childhood development is essential to promote cognitive, social, emotional, and physical development as well as to reduce systemic poverty and inequalities (Shonkoff and Phillips, 2000).

1.2 Tools to Measure ECD.

Measuring ECD presents several difficulties due to its multidimensional nature. Comprehensive assessments of ECD typically require highly trained professionals and significant administration time, making them unsuitable for large-scale population monitoring. To capture information about children's achievements, UNICEF, in collaboration with a technical advisory group, developed the ECDI, a 10-item index. In 2009, it was added to the Multiple Indicator Cluster Surveys (MICS) and it has been used in over 70 countries.

The ECDI aims to measure the overall developmental status of children within the physical, literacy-numeracy, social-emotional, and learning domains. It consists of specific questions for mothers/caregivers about their children's development. Subsequently, UNICEF developed a new methodology involving consultations with experts, partner agencies, and national statistical authorities. When early childhood development became part of the Sustainable Development Goals (SDGs) of the Agenda 2030, SDG indicator 4.2.1 was chosen to monitor the improvements towards this target. An updated version of the ECDI was implemented in response to the requirements of SDGs monitoring, namely ECDI2030. The ECDI2030 captures the achievement of key developmental milestones by children aged 24 to 59 months.

The index covers 12 sub-domains under three domains of ECD including health, learning, and psychosocial well-being. The index includes 20 questions for mothers or primary caregivers to assess children's behavior, skills, and knowledge in everyday situations. ECDI2030 is designed to assess a child's overall level of development across three dimensions: health, learning, and psychosocial well-being. Unlike the MICS, the ECDI2030 was specifically designed and validated to generate estimates for reporting on SDG indicator 4.2.1.

Additionally, the ECDI2030 provides broader and more comprehensive content coverage, including a larger number of developmental sub-domains that enable a more comprehensive and accurate assessment (UNICEF Technical manual, 2023)**.**

All things considered, this study aims to promote a new early childhood composite index ECDI(i) for tracking children's development at the global level, by investigating inputs that affect it. The expected index should incorporate key indicators able to capture children's capabilities in three main dimensions: health, learning, and psychological well-being.

2. Methodology

The development of a new composite indicator follows four stages:

(1) Definition of the phenomena
(2) Selection of individual indicators
(3) Standardization
(4) Aggregation

According to the relevant literature (Murgatroyd and Spengler, 2011), "*Early Child Development*" could be defined along three different dimensions: *Health*, *Psychological Well-Being*, and *Learning*. The composition of these dimensions provides a multidimensional definition of the ECD.

The reasons behind the elaboration of a new composite indicator are grounded in the necessity to construct a tool capable of measuring the inputs required for a

healthy and safe child development. The current ECDI2030 devised by UNICEF is limited to assessing whether children are on track for the three dimensions while the need to measure inputs is paramount as it makes possible an early identification of developmental challenges.

Moreover, the measure of those dimensions has other upsides such as providing a comprehensive assessment of the environment and living basic conditions of children, the possibility of being implemented remotely using available data and, lastly, it can foster targeted interventions.

2.1 Computation of the new ECDI(i)

The conceptual framework that guided the selection of dimensions included in the new index includes:

A. The capability approach (Sen, 1999), a suitable foundation for analyzing the multiple factors that influence capabilities and human well-being by considering the conversion factors.
B. The WHO guidelines provide recommendations to caregivers, health professionals, policymakers, and stakeholders for identifying areas of concern and strengthening policies to better address ECD (WHO guideline, 2020).

This composite index was developed by collecting data from the UNICEF warehouse and was tested on 28 countries selected in accordance with available data. Domains and sub-domains keep track of the three dimensions identified in the ECDI2030, indeed the final indicator is the result of the composition of three different indicators: (**H**) *Health*; (**P**) *Psychological Well-Being*; (**L**) *Learning*.

The indicators **H** and **P** were the results of the aggregation of different composite indicators. Once every individual indicator was collected, the composite indicators were built by using the **MPI** methodology. In the case of both **H** and **P** the process of standardization occurred only in the first stage of aggregation whereas in the subsequent composition steps the **Z**-matrix is already given and does not need to be computed once again.

Table 1 - *Health dimension indicators.*

Indicator	Domain	Subdomain	Individual Indicators
Health	***Maternal/Child Health***	*M&C Risk Factor*	*- Prevalence of Anaemia in pregnant Women*
			- (%) Preterm births
		Breastfeeding	*- Exclusive breastfeeding 0-5 months*
			- Continued Breastfeeding 12-23months
	Child Nutrition	*Child Food Poverty*	*- Severe child food poverty*
			- Moderate child food poverty
			- Minimum dietary diversity
			- Minimum Meal Frequency
		Child Malnutrition	*- Wasting: 0–59 months*
			- Overweight 0–59 months
			- Stunting:0–59 months
	Child Mortality	*Childhood deaths*	*- Under-5 mortality rate*
			- Infant Mortality rate
		Immunization preventable disease	*- DTP3: diphtheria, pertussis and tetanus vax*
			- Polio3: 3 doses of the polio vax
			- MCV1: 2 dose of measles vax
	Security and Safety	*Pregnant Status*	*- Antenatal care (at least one visit)*
			- Institutional delivery
		Access to Service	*- Sanitation services*
			- Drinking-water services (%)

Table 2 – *Psychological Well-Being dimension indicators.*

Indicator	Domain	Subdomain	Individual Indicators
Psychological Well-Being	**Responsive Caregiving**	*Environment and Caregiver*	*- (%) children's book*
			- (%) children's toys
			- Stimulation by parents
			- Children with inadequate supervision
			- Violent Discipline
		Care-seeking	*- Careseeking for diarrhea*
			- Careseeking for respiratory infection

Table 3 – *Learning dimension indicators.*

Indicator	Domain	Individual Indicators
Learning	**Education**	*- Adjusted net attendance rate (ANAR)*
		- Attendance in early childhood education
		- Positive Discipline 1-4

2.2 Mazziotta-Pareto Index

To aggregate individual indicators into composite indicators we used the Mazziotta-Pareto index (MPI). The MPI is widely used to calculate multidimensional phenomena. Given the original matrix $\mathbf{X=\{x_{ij}\}}$ with *n* rows and *m* columns where (Mazziotta and Pareto 2020):

$$M_{xj} = \frac{\sum_{i=1}^{n} x_{ij}}{n} \qquad Sx_j = \sqrt{\frac{\sum_{i=1}^{n}(X_{ij} - M_j)^2}{n}} \tag{1}$$

The matrix $\mathbf{Z=\{z_{ij}\}}$ is composed:

$$z_y = 100 \pm \frac{(x_y - M_{xj})}{S_{xj}} 10 \tag{2}$$

where x_{ij} is the value of the indicator *j* for the unit *i* while the values of **M** and **S** are set to a defined value of 100 and 10 respectively and the polarity of the ± sign depends on whether the phenomena is positive or negative. Given the matrix $\mathbf{Z}=\{z_{ij}\}$ the vector $\mathbf{CV}=\{cv_i\}$ is computed where:

$$cv_i = \frac{S_{zj}}{M_{zj}} \tag{3}$$

And:

$$M_z = \frac{\sum_{j=1}^{m} z_{ij}}{m} \qquad S_{zj} = \sqrt{\frac{\sum_{j=1}^{m}(z_{ij} - M_{zj})^2}{m}} \tag{4}$$

The composite index is then obtained using the following formula:

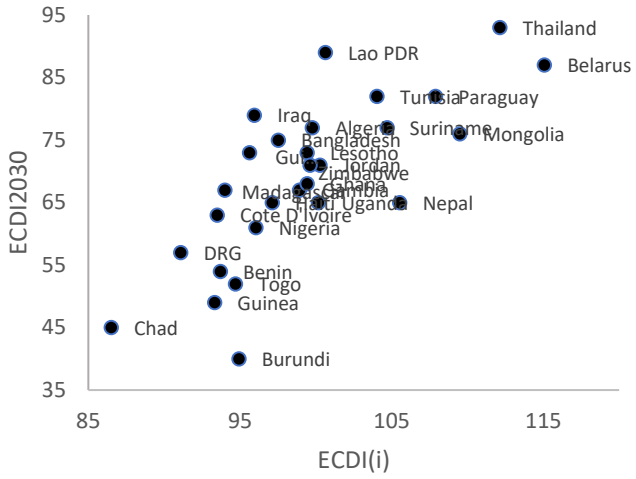
$$MPcv_i = M_{zi}(1 - cvi^2) = M_{zi} - S_{zi}\, cv_i \tag{5}$$

The arithmetic mean of the standardized indicators is corrected by subtracting a quantity (the product of $S_{zi}\, cv_i$) proportional to the standard deviation (Mazziotta and Pareto 2017). In this way units with similar standardized values are less penalized.

3. Results

To understand the effectiveness of ECDI(i) we compared it with ECDI2030, thus performing a correlation analysis. As Figure 1 shows, we found a positive correlation between the two indices.

Figure 1 – *Scatterplot between ECDI(i) and ECDI2030.*



The value of the Pearson Coefficient (r) is equal to 0.705 suggesting a substantial agreement between the two measures. Furthermore, a small p-value (< 0.001) indicates that the correlation is statistically significant. These findings reinforce the reliability of the ECDI(i) as a tool to assess early childhood development. Although the two indices are not interchangeable, this result suggests that the ECDI(i) is capable of assessing and measuring whether the inputs (such as endowments, opportunities, and planned interventions) have reached a satisfactory level for the child's development. Therefore, the ECDI(i) might be a useful complementary tool that makes it possible to draw predictions about eventual outcomes in children's development. Despite their different approaches, it can be inferred that the high correlation between ECDI(i) and ECDI2030, (one based on inputs and the other on outcomes), may be linked to the following explanation:

(a) Since ECD is a multidimensional process where inputs influence outcomes, when countries prioritize inputs, this is more likely to positively impact the overall outcomes of children's development. As suggested by the WHO, equitable access to high-impact and quality health and education services (an

input) may support child cognitive development (an outcome) (WHO guideline, 2020). In fact, countries with high MPI for each of the three dimensions are at the top of the ranking for both ECDI2030 and ECDI(i) (Table 4) (e.g., Belarus: ranking position n°1 and n°3 in ECDI(i) and ECDI203, respectively)

(b) Both ECDI(i) and ECDI2030 assess ECD based on the same framework (e.g., Health, Psychological well-being and Learning) resulting in capturing similar aspects of the ECD multi-faceted phenomenon.

Furthermore, country's ranking is shown in Table 4 by using both ECDI(i) and ECDI2030, where it can be noticed a slight but significant change in the rank positions. Ranking is a key point to compare children's living conditions between countries. Furthermore, the analysis of the index's subdimensions may provide valuable insights for policymakers to employ targeting strategies and intervention programs.

The result of this work also depends on the fact that countries with the highest scores coincide between the two indicators, as in the case of Belarus, Thailand, and Paraguay. The only exception is Mongolia which, in ECDI(i), replaces Lao PDR. In any case, the latter still maintains a score above the limit set by the MPI (100.6) for ECDI(i).

The same congruence can be found at the bottom of the ranking, where the Democratic Republic of Congo replaces Burundi, which ranks 25th in the ECDI(i) and scores well below the MPI threshold (94.3). On the other hand, when extremes are excluded, there is a significant difference in the ranking order of countries.

This behavior makes the development of a new indicator highly relevant to establish and determine distinct intervention strategies (and resource allocation) depending on the instrument used. For instance, Uganda scores above the MPI threshold in ECDI(i), while it ranks among the lowest countries in ECDI2030. The inconsistencies observed in the Ranking order may have the following explanations:

(A) Different methodologies used to compute data, result in a different assessment of the ECD phenomenon.

(B) The three dimensions of ECDI(i) do not include data exclusively related to children. The composite indices contain data regarding (i) health and well-being of the mother and (ii) the environmental conditions in which the child is developing (stimulating environment, violent education, and caregivers, among others).

In conclusion, based on these findings and considering that ECD is a complex and multidimensional phenomenon, the authors of this paper believe that a holistic approach is needed to integrate the current framework of developmental conditions by reviewing the input dimensions that causally determine the possibility of healthy child development.

Table 4 – *Rank comparison between ECDI(i) and ECDI2030.*

Country	**ECDI(i)**	Country	**ECDI2030**
Belarus	**115,08**	**Thailand**	**93,00**
Thailand	**112,14**	**Lao PDR**	**89,00**
Mongolia	**109,51**	**Belarus**	**87,00**
Paraguay	107,90	Paraguay	82,00
Nepal	105,54	Tunisia	82,00
Suriname	104,71	Iraq	79,00
Tunisia	104,04	Algeria	77,00
Lao PDR	100,63	Suriname	77,00
Jordan	100,28	Mongolia	76,00
Uganda	100,18	Bangladesh	75,00
Algeria	99,78	Guinea−Bissau	73,00
Zimbabwe	99,62	Lesotho	73,00
Lesotho	99,43	Jordan	71,00
Ghana	99,43	Zimbabwe	71,00
Gambia	98,93	Ghana	68,00
Bangladesh	97,53	Gambia	67,00
Haiti	97,13	Madagascar	67,00
Nigeria	96,05	Haiti	65,00
Iraq	95,96	Nepal	65,00
Guinea−Bissau	95,63	Uganda	65,00
Burundi	94,93	Cote D'Ivoire	63,00
Togo	94,71	Nigeria	61,00
Madagascar	94,00	DRG	57,00
Benin	93,71	Benin	54,00
Cote D'Ivoire	93,51	Togo	52,00
Guinea	**93,34**	**Guinea**	**49,00**
DRG	**91,10**	**Chad**	**45,00**
Chad	**86,52**	**Burundi**	**40,00**

4. Conclusion

A comprehensive monitoring framework for ECD should include indicators that measure both inputs and outcomes. Factors such as children's nutritional status, access to early learning opportunities, and exposure to responsive caregiving are important inputs that affect early child development. These inputs have an influence on developmental outcomes among children. The work of this research allows us to conclude that:

I. There is linear and positive correlation between ECDI(i) and Unicef's ECDI.
II. The indicator considers inputs needed for child development, although there is a need to collect more data and individual indicators.
III. A significant change in ranking is necessary to understand the degree of early child development and possibly target research, studies, and operations.

However, given the preliminary nature of these results, further development is required and necessary. Especially more data is needed for existing indicators, and possibly, the development of new indicators capable of capturing other essential aspects of child development. Indeed, along the process of data collection, a difficulty in collecting data was enconutered for many relevant indicators. In developing the ECDI(i), a recurring problem concerns the lack of data for many countries.

This problem forced us to reduce the sample of countries and the number of individual indicators. In fact, as highlighted in Table 5, some essential indicators that should be included (Shonkoff and Phillips, 2000; WHO, 2020) to build a more accurate tool have not been included due to a lack of available data.

However, the preliminary nature of the results emphasizes the need for further development and data collection, as existing indicators may require more data and new indicators to capture additional crucial aspects of child development. Many countries lack data for relevant indicators, limiting a more robust and comprehensive analysis of ECD.

Table 5– *Not included indicators due to lack of available data.*

Health	Psychological Well-Being	Learning
-Maternal consumption of Iron and folate	Maternal mental health	-Child (0-5) literacy skills
-Micronutrient deficit	-Responsive care by father	-Child (0-5) numeracy skills
-ANC and IPT3 coverage for pregnant women	-Labor force participation rate	-Mother's literacy rate

References

BLACK M.M, WALKER S.P., FERNALD L.C., ANDERSEN C.T., DIGIROLAMO A.M., LU C., MCCOY D.C., FINK G., SHAWAR Y.R., SHIFFMAN J., DEVERCELLI A.E., WODON Q.T., VARGAS-BARÓN E., GRANTHAM-MCGREGOR S. 2017. Early childhood Development Coming of Age: Science through the Life Course, *Lancet*, Vol. 389, No. 10064, pp.77-90.

GRANTHAM-MCGREGOR S., CHEUNG Y. B., CUETO S., GLEWWE P., RICHTER L., STRUPP B. 2007. Developmental potential in the first 5 years for children in developing countries, *Lancet* Vol. 369 (9555), pp.60-70.

HECKMAN J.J. 2011. The Economics of Inequality: The Value of Early Childhood Education, *American Educator*, Vol. 35, No. 1, pp.31-35.

MAZZIOTTA M., PARETO A. 2017. Synthesis of Indicators: The Composite Indicators Approach. In Maggino, F. (Ed.) *Complexity in Society: From Indicators Construction to their Synthesis*, Social Indicators Research Series, Vol 70, Springer Cham.

MAZZIOTTA M., PARETO A. 2020. *Gli indici sintetici*. Torino: Giappichelli.

MURGATROYD C., SPENGLER D. 2011. Epigenetics of Early Child Development, *Frontiers in Psychiatry*, Vol. 2, No. 16.

SEN A. 1999. *Development as freedom*. Oxford: University Press.

SHONKOFF J. P., PHILLIPS D. A. 2000. From Neurons to Neighborhoods. *The Science of Early Childhood Development*, National Academies Press.

UNICEF. 2023. The Early Childhood Development Index 2030: A New Measure of Early Childhood Development. *UNICEF Technical manual*.

WALKER S.P., WACHS T.D, GRANTHAM-MCGREGOR S., BLACK M.M., NELSON C.A., HUFFMAN S.L., BAKER-HENNINGHAM H., CHANG S.M., HAMADANI J.D., LOZOFF B., GARDNER J.M., POWELL C., RAHMAN A., RICHTER L. 2011. Inequality In Early Childhood: Risk and Protective Factors for Early Child Development, *Lancet*, Vol. 378, No. 9799, pp. 1325-38.

WHO. 2020. Improving Early Childhood Development. *WHO Guideline*.

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