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Granularity: Macroeconomics and Beyond

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Abstract

Granularity, a macroeconomics concept, explains how small economic shocks can cause significant fluctuations in the broader economy. The granularity hypothesis posits that large firms' shocks disproportionately impact the economy, countering the idea that these shocks are balanced out at the macro level by the law of large numbers. Granularity, indicating the presence of both few large and many small firms, implies that firm size distribution adheres to a power law, thereby linking granularity and power laws. Power law distributions are common across various scientific fields, yet the associated concept of granular size remains unexplored. We explain that computing the granular size opens up new research opportunities in a wide range of scientific areas where quantities follow a power law distribution.

Subject Areas

Macroeconomics, Statistical Physics, Econophysics

Keywords

Granularity, Granular Residual, Granular Size, Power Laws

1. Introduction

Key to macroeconomics research is understanding why small shocks can cause large economic fluctuations. Proposed explanations include: the role of investment and capital in real business-cycle models [1]; Keynesian multipliers [2]-[6]; credit market disruptions affecting firms, households, or banks [7]-[10]; the influence of real and nominal rigidities and their interplay [11]; and challenges posed by inadequate or constrained monetary policy [12]-[14]. However, the study of how minor shocks to individual firms or sectors ripple through the economy via economic connections has been overlooked, despite its significant potential [15].

A shock to just one firm or sector can significantly impact the wider economy by decreasing output among interconnected businesses in an input-output network. This impact was previously undervalued, as it was believed that unique shocks to firms or sectors would neutralize at the macroeconomic level due to the law of large numbers. However, the firm-idiosyncratic shocks' perspective has recently attracted theoretical attention.

Xavier Gabaix [16] shows that in an economy with firm sizes distributed according to a heavy-tailed pattern, shocks to large firms do not get neutralized by those to smaller firms. This finding challenges the conventional use of the law of large numbers and suggests that firm-specific shocks can cause notable macroeconomic variations. This concept is known as the granularity hypothesis.

Furthermore, input-output connections can weaken the law of large numbers' influence by causing widespread economic impacts through shocks to crucial supplier sectors [17]-[20]. Network-based models excel in analyzing these shock effects due to their empirical applicability, underlining the mechanisms' importance [15]. The role of production networks in shaping economic outcomes is gaining acknowledgment in theory and practice. These networks facilitate the spread of shocks throughout the economy, transforming minor disturbances into significant macroeconomic fluctuations. Ongoing research focuses on empirically testing and quantifying the impact of shocks occurring in these networks.

Granularity in firms arises from the mix of a few large and many small firms, making an economy "granular" rather than "smooth", which would be the case if all firms were of equal size. The "granular residual" represents the combined impact of unique shocks to firms that do not average out, scaled by size. This concept emphasizes the part of the business cycle influenced not just by broad economic shocks but also by specific disturbances at the firm level. It particularly accounts for the effects of shocks to the largest firms, with the "granular size" providing a measure for this assessment.

The existence of large "grains" requires a distribution with a heavy right tail, characteristic of a power law, allowing these firms to significantly influence the business cycle, unlike a scenario with uniformly sized firms. A distribution with this heavy-tailed nature implies that shocks to the largest firms will not just average out but will affect GDP dynamics. If firms were uniformly sized and reacted identically to shocks, the granular residual would be negligible. However, a significant granular residual emerges when large firms are disproportionately affected by shocks, highlighting their impact on the economy.

Although power laws predate and are distinct from the concept of granularity, both principles are relevant to hierarchical systems. It is important to note the close relationship between granularity and power laws: the presence of a heavy-tailed distribution in hierarchical systems enables exceptionally large units to exist [21] [22].

The contribution of this paper is to show that the relationship between granularity and power law distributions, which provides a novel viewpoint on macroeconomics, can also open up new research pathways in a variety of domains characterized by power law distributions.

2. Materials and Methods

2.1. Power Laws

A power law indicates that the likelihood of a certain value inversely correlates with that value elevated to a specific exponent. Essentially, when one quantity varies, the other adjusts in a consistent ratio, regardless of the initial amount. On a log-log plot, a power law appears as a straight line, and the line's steepness, known as the Pareto exponent, measures this relationship [23].

Distributions rarely follow a power law across their entire range; they usually do so between specific minimum and maximum values, creating a "power law tail" [24]. The Pareto exponent plays a critical role in this scenario by measuring the "thickness" of the distribution's right tail. The thickness indicates the prevalence of higher values: the lower the Pareto exponent, the thicker the tail [25].

2.2. Granular Residual

The granular residual sums up the size-weighted individual shocks to the largest firms, termed as "big grains". When firm size distribution adheres to a power law, indicating a heavy right tail, it suggests that firm-level shocks are important and do not neutralize but instead affect the business cycle. Thus, the granular residual measures the effect of these individual firm-level shocks.

The impact of the granular residual on overall economic fluctuations is assessed by regressing the GDP per capita growth rate against current and past residuals and then quantifying the explained variance with the R^2 statistic. Analyzing a country's growth rate against the granular residual of its largest firms reveals that the adjusted R^2 surpasses these firms' GDP contribution. This indicates that shocks to large firms significantly influence the business cycle [16].

2.3. Granular Size

As seen, the granularity hypothesis posits that economic shocks are not evenly distributed across firms but are rather dominated by a few large ones, challenging the idea that firm-specific effects are neutralized in the aggregate. This is reflective of firm size distributions that typically follow a power law. The granular residual, which aggregates size-weighted shocks from the largest firms, can be misrepresented if the count of large firms is not accurately adjusted [26]. Hence, the importance of determining the granular size.

The "granular curve" represents the function $C(L)$, which shows the average cumulative explanatory power, and its value is

$$C(L)=\frac{1}{Q}\sum_{K=1}^{Q}R^2(K,L). \quad (1)$$

Here, Q is an arbitrary number of firms, and L signifies the count of top-ranked firms to be excluded from the sample and substituted with firms ranked from $Q + 1$ to $Q + L$. For every value of L, an equivalent set of regression analyses is performed using the granular residual as the sole explanatory variable.

$C(L)$ represents the average R^2 value obtained from Q regressions at each level of L, tracking how the explanatory power of the model changes as the largest firms are progressively excluded, which is achieved by incrementally increasing L. Thus, the curve $R^2(K, L)$ is analyzed to understand how the model's explanatory power evolves with an increasing firm count K and varying counts of the largest firms L.

The aim is to analyze the performance of the curve $R^2(K, L)$ based on varying L, which is the count of top-ranked firms removed from the sample and substituted with firms ranked $Q + 1$ to $Q + L$. For each level of L, we run Q regressions using the granular residual as the explanatory variable. $C(L)$ then measures the average R^2 value from these Q regressions at each level of L.

Simultaneously, we run identical regressions without applying firm size weights. The granular size is identified at the point where the granular curve $C(L)$ matches the adjusted R^2 of these unweighted regressions. Essentially, the granular size reveals how many of the largest firms (grains) can be excluded from the sample without diminishing the average adjusted R^2, thereby maintaining the explanatory power of the granular residual across all possible $K \leq Q$.

In short, the equal-weight curve measures the impact of shocks from firms on the business cycle, assuming all firms are of equal size, thus giving more weight to smaller firms. Removing the L largest firms from the analysis incrementally transitions the observed granular curve $C(L)$ towards the equal-weight curve. The point of intersection between these curves indicates the granular size K^*. Figure 1 provides a visual representation based on hypothetical data.

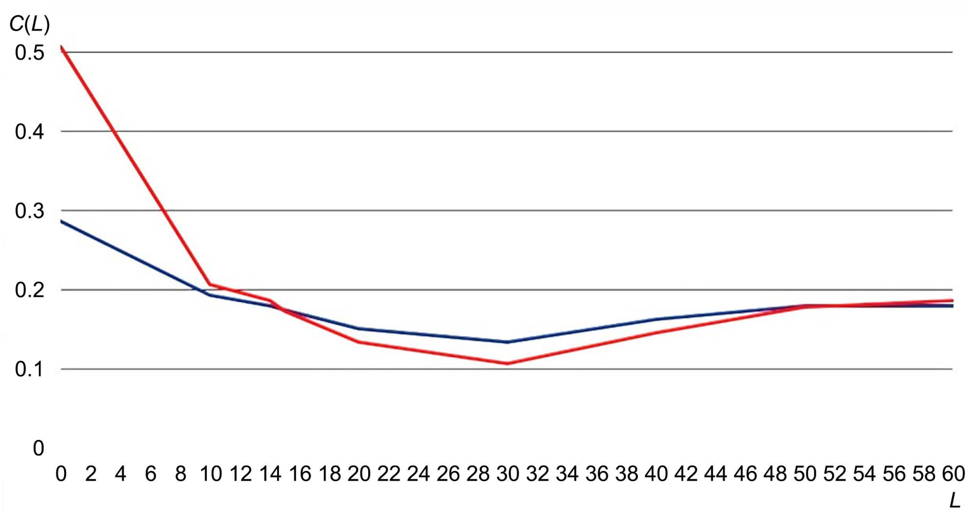

Figure 1. Granular size. The equal-weight curve is depicted in blue, while the granular curve is illustrated in red. This hypothetical quantity has a granular size of $K^* = 15$, which corresponds to the value of L at which the granular curve $C(L)$ initially intersects the equal-weight curve.

An alternative granular size calculation method [21] contrasts uneven firm rankings with a uniform firm distribution. The process is as follows: First, generate, say, 50 series of 10,000 values each, drawn from a standard normal distribution, corresponding to the sample size of firms. Then, rank these values. Next, calculate the decay rates between consecutive ranks (e.g., from rank 1 to 2, 2 to 3, etc.). Afterward, determine the average and standard deviation of these decay rates across the series. Establish a standard deviation range above and below each average decay rate between adjacent ranks. Finally, evaluate the firm rank decay rates within these ranges.

3. Applications

3.1. Application in Macroeconomics

As observed, the notion that business cycle fluctuations originate from microeconomic granularity is increasingly accepted. Support for this theory comes from two economic features [27]: the lopsided distribution of firm sizes [16] [27]-[30] and the unbalanced pattern of input-output connections [18] [31]-[33].

Previously, the granularity hypothesis [16] was overlooked by studies arguing that the law of large numbers causes individual firm shocks to diversify away, resulting in negligible overall effects [34] [35]. Yet, this conclusion is only valid when firms are roughly similar in size. It does not apply when the distribution of firm sizes follows a power law.

Research using firm-level data has shown that large firms' idiosyncratic shocks significantly influence GDP fluctuations in various countries, including the U.S. [16] [36], Europe (Austria, Belgium, Finland, France, Germany, Italy, Portugal and Spain) [37], the UK [38], Germany [39], France [28], Spain [40], China [41], Russia [42], Brazil [43], Australia [27], Korea [44], Finland [30], Chile [45], Canada [46], Sweden [47], Italy [48], Ireland [49], Hungary [50], Morocco [51], and Kazakhstan [52]. This provides global support for the granularity hypothesis. Rare cases of conflicting evidence [53] [54] have been contested [55].

3.2. Application in Particular Markets

The concept of granularity has been applied across various markets, moving from a broad aggregate focus on the business cycle to specific areas such as exports [56] [57], investment [58]-[60], the labor market [55] [61], the banking sector [62] [63], and international trade [64]-[67].

Volumes exported internationally are governed by a power law, not a Gaussian distribution. Therefore, the largest countries have a disproportionate impact on global inflation. Because power laws are present, granularity is expected, and the granular size can be determined. Business cycle shocks can be communicated between countries via inflation spillovers. Countries responsible for the majority of international trade links determine a share of inflation spillovers that exceeds their involvement in global trade, resulting in granular inflation spillovers [22]. When granularity's derived idea of granular size was applied, it was discovered that eight countries have a greater impact on world inflation than their relative size in global trade (the U.S., China, Germany, the U.K., Japan, France, Italy, and Netherlands) [22]. These big grains account for the majority of inflation spillovers. The policy implications are that other countries' central banks should closely watch these eight major grains when implementing domestic monetary policy.

The granularity concept, initially applied to firms, extends to cities, highlighting the presence of a few large cities amidst many smaller ones [68]. City sizes adhere to Zipf's law, a power law with a Pareto exponent of one, enabling calculation of granular city size. This indicates that large cities significantly influence the business cycle beyond their physical size. Analysis revealed that the U.S. granular city size encompasses three major metropolitan areas [68]. Traditional business cycle analyses at national or regional levels overlook the nuanced impact of city-level dynamics. Recognizing that cities have a disproportionate influence on the business cycle allows for a deeper understanding of their economic contributions and challenges, leading to more effective, targeted growth and resilience strategies.

3.3. Application outside Economics

Power laws are widespread in both nature and society [23]. Given their prevalence, the granular size concept is applicable wherever a power law is observed, presenting vast research opportunities. Researchers are encouraged to calculate the granular size for any quantity distributed according to a power law and then analyze its implications within their specific research context.

Here is an example of how this has already been done. Consider power laws in biology. For example, power laws determine the abundance distribution of birds based on rank [69]. The granular size can therefore be calculated [21]. The granular size notion, drawn from economics, is used here to replace corporations with birds. The granular size of rank abundance distribution was determined to be 13 bird species. The inference here is that the granular size refers to the number of species that, like large firms in an economy, have a disproportionately large impact on their ecosystem [21].

Now consider an idea to elaborate on. In chemistry, the periodic law outlines chemical relationships among elements, while a statistical regularity in the form of a power law connects atomic number to atomic weight (isotope-weighted average) in the periodic table [70]. By analyzing current periodic table data, the Pareto exponent of this power law can be determined. This statistical relationship complements Mendeleev's periodic law and aids in discovering new elements. Calculating the granular size using this power law could help speed up the search.

4. Conclusions and Prospects

The concept of granularity, potentially a Nobel-worthy breakthrough, has revolutionized the field of macroeconomics and has increasingly informed research across various economics fields. Its application extends beyond economics, given its relevance to any phenomena characterized by power law distributions, heralding a new frontier for scientific inquiry across disciplines.

This paper has emphasized the central role of granularity in understanding economic fluctuations, showing its broad applicability from the granular impacts of large firms on GDP to the influences of major exporting countries on global inflation. It has also ventured into novel territories, showing how granularity shapes urban landscapes and could even refine our search for new elements in chemistry.

As we continue to explore and apply the granular size concept, the prospects for further groundbreaking research are vast, promising insights that could clarify our understanding of both macroeconomic dynamics and the fundamental structures underpinning various fields of study.

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Conflicts of Interest

The author declares no conflicts of interest.

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