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Interfaces with Other Disciplines

Attributing credit to coauthors in academic publishing: The 1/n rule, parallelization, and team bonuses[☆]

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ABSTRACT

Universities looking to recruit or to rank researchers have to attribute credit scores to their academic publications. While they could use indexes, there remains the difficulty of coauthored papers. It is unfair to count an n -authored paper as one paper for each coauthor, i.e., as n papers added to the total: this is “feeding the multitude”. Sharing the credit among coauthors by percentages or by simply dividing by n (“1/n rule”) is fairer but somewhat harsh. Accordingly, we propose to take into account the productivity gains of parallelization by introducing a parallelization bonus that multiplies the credit allocated to each coauthor.

It might be an idea for coauthors to indicate how they organized their work in producing the paper. However, they might systematically bias their answers. Fortunately, the number of parallel tasks is bounded by the number of coauthors because of specialization and the credit is bounded by a limiting Pareto maximum. Thus, the credit is given by $(N+2)/3n$ for N parallel tasks. As there may be, at most, as many parallel tasks as co-authors, credit allocated to each coauthor is given by $(n+2)/3n$, that varies between $2/3$ of a single-authored paper for two coauthors and $1/3$ when the number of coauthors is very large. This is the “maximum parallelization credit” rule that we propose to apply.

This new approach is feasible. It can be applied to past and present papers regardless of the agreement of publishing houses. It is fair and it rewards genuine cooperation in academic publishing.

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1. Introduction

In most countries scholars are evaluated by their academic output. Most scholars coauthor their papers. This is standard practice and desirable in many fields of science. Multi-authorship is a feature of scientific research which is not commonplace in other domains such as art (Galenson, 2007; Nabout et al., 2015; Sahu & Panda, 2013). Multi-authorship is a growing practice (Wuchty, Jones, & Uzzi, 2007)¹ and is often perceived as a sign of quality research. This excerpt is from Narin and Hamilton (1996 p. 296):²

Counts of coauthorships, and especially international coauthorships, are an indicator of quality, and that scientists who cooperate with their colleagues in other institutions and overseas are more likely to be doing quality research than those that are relatively isolated.

Laband (1987) reports that the acceptance rate of coauthored papers is higher and such papers are cited more. Hsu and Huang (2011) find a correlation between collaboration and higher impact. Harsanyi (1993) discusses multi-authorship as a source of prestige. Moreover, it might be argued that multi-authored manuscripts allow economies of scale. For example, Durden and Perri (2003) think that coauthorship,³ increases total and per capita productivity in economics. Moreover, it may be more difficult to get published when the paper is single-authored: Gordon (1980) reports that the leading journal *Astronomy and Space Science* accepted only 63% of single-authored papers but 81% of multi-authored papers and 100% of papers with more than six coauthors (although it should be said that very few papers have more than three coauthors).⁴ The rate of multi-authorship may be highly variable across disciplines (Wang, Wu, Pan, Ma, & Rousseau, 2005).

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¹ See also the answer of Brandão (2007).

² On international coauthorship, see Narin, Stevens, and Whitlaw (1991).

³ And membership of the American Economic Association...

⁴ The number of coauthors may be very large, up to 5154 coauthors in the recent Aad et al.'s (Aad & ATLAS Collaboration, CMS Collaboration, 2015) paper, the world record.

An anonymous referee suggested to us that multi-author papers are more likely to be accepted possibly because multiple authors tend to criticize each other and dis-

However, for Zi-Lin (2009), internationally coauthored papers “[do] not have more epistemic authority”. Coauthorship is not a panacea. It may slow down the reviewing process. For example, Hartley (2005) shows that, in psychology journals, single-authored papers are reviewed faster than multiple-authored ones. Coauthoring does not prevent bad papers (de Mesnard, 2010) or simply unreadable papers (Remus, 1977) from being produced. Throughout this paper we work on the assumption that coauthors are rational: if they cooperate, it is because they derive a benefit, either in terms of quality or in terms of time and effort. Therefore, cooperation is simply a means to obtain a paper of a given level of quality at a lower cost.⁵

In the context of academic evaluation, and when no information about each author's contribution is available, a multi-authored paper is generally counted today as one paper for each coauthor, which means that the n -coauthored paper is counted for n papers. This is unfair: counting each paper coauthored by many researchers as one paper each leads to an obvious bias. For example, consider three papers and three scholars. Scholar b has produced “Beta” and during that time, scholars a_1 and a_2 have coauthored papers “Alpha1” and “Alpha2”. If an unsophisticated count is made we have three papers: “Beta” appears in b 's curriculum vitae, which is fair enough. But “Alpha1” and “Alpha2” appear in the curricula of both a_1 and a_2 . Therefore, if n researchers produce P papers together, they seem to have produced nP papers, a phenomenon we might call *feeding the multitude*, to use a biblical metaphor, with no disrespect intended. Moreover, coauthors a_1 and a_2 on the one hand and b on the other hand are not treated equally. This is why some scholars may go too far by forming what we term *publication club* to artificially boost their output. A publication club⁶ is a rather small group of scholars who mutually agree, not to collaborate on writing a paper in common, but to cosign each other's papers, even if they have not really been involved in writing them. This obviously results in more coauthorship.⁷

All authors want to be published in the leading journals, but this may turn into a farce, in the words of McDonald and Kam (2007). Even if the academic evaluation system ignores coauthorship, powerful incentives for coauthorship will be created, leading immediately to the idea of “publication club”. A good strategy for any scholar wanting to increase his score is to join a publication club. This raises the difficult question of whether coauthorship is necessary, as in a publication team, or is artificial and even completely fake as in publication clubs. Publication teams are a growing phenomenon, which is a good thing (Rey-Rocha, Garzon-Garcia, & Martin-Sempere, 2006), but the development of publication clubs could prove very harmful.

Although it is impossible to prevent the formation of publication clubs, or to eradicate them, there remains the possibility of reducing their impact by “punishing” multi-authorship. Imagine a paper written by a single author. It is obviously attributed to him in full. Now, imagine a paper written by two coauthors. Should we count the paper for zero to each coauthor because neither of

them is able to produce the full paper in a finite time? This would be plainly unfair. Should we attribute the full paper to each coauthor? For example, should we count one paper for the coauthor specialized in theory and one paper for the coauthor specialized in econometrics, although neither of them has produced the full paper alone? This leads to counting two papers in total although only one has actually been produced. Or should we divide the merit by two, counting only 1/2 paper for each coauthor (and one paper for the total)? This last solution is the “1/ n ” rule where n is here the number of coauthors.

Even if this might seem fair, each of the two coauthors could rightly argue that he/she has done his/her full job and contributed decisively to the paper — the first one in thinking about and writing the theory and the second one in conducting the tests. Is each author's merit less than for a single authored paper? Thus, we propose to reward coauthors who are more efficient, that is, to reward justified specialization in a team by means of a *parallelization bonus* that takes into account the parallelization induced by collaboration among specialists.

However, as the degree of parallelization cannot be determined exogenously discipline by discipline, we could propose that each team of coauthors indicates how the labor was organized to produce the paper. Unfortunately, coauthors may systematically bias their answers in order to increase the parallelization bonus and receive a larger allocation for each coauthor. Nevertheless, we will be able to demonstrate that a limitation mechanism operates—a limiting Pareto maximum enabling us to define a parallelization bonus.

For the first time, to our knowledge, we will look inside the “machine” by “lifting the hood”, that is, by taking into account the organization of tasks necessary to write a paper. This approach will concern academic disciplines in which single-authorship is a credible possibility, but also other disciplines in which teams may run to dozens and even thousands of coauthors as in medicine and where subtle rules among signatories allow specialists to infer who has done what.

2. Sharing the credit: contribution weights and 1/ n rule

Even if the connection between collaboration and productivity is unclear (Fox, 1983), it may be argued that coauthorship divides the effort: it is undoubtedly unreasonable to count a single paper produced by a team of n coauthors, as n papers, one for each of the n coauthors. A paper produced by a team of $n > 1$ scholars cannot be worth n times a paper produced by a single scholar.⁸

We never claim that the number of publications is a sign of productivity or performance for researchers⁹ but the formation of publication clubs should be prevented. This is why the merit attributed to the coauthor i of a given academic paper p must be shared among the coauthors. In general terms, for an academic paper p , the credit system for a nonempty set Ξ_p of coauthors is a vector \mathbf{A}_p of dimension n where $\{n = \text{card}(\Xi_p) \in \mathbb{N} \setminus 0\}$ such that a credit A_{p_i} is attributed to each coauthor $i \in \Xi_p$ by the following mapping:

$$f : \Xi_p \rightarrow [0, 1]^n : \{i\}_{i \in \Xi_p} \mapsto \mathbf{A}_p$$

For example, a credit of $A_{p_i} = .45$ means that coauthor i of paper p is credited of 45% of a full paper. In what follows, we omit the

cuss their publication, so that a kind of internal evaluation improves the manuscript before submission much more effectively than a single author can do.

⁵ Cooperating may generate coordination costs: if coordination costs are higher than the gross benefit derived from cooperation, the paper will not be written in cooperation. This topic will not be examined in this paper.

⁶ The term “club” is not here used in Buchanan's sense (Buchanan, 1965) but in the sense of “brotherhood,” “fraternity” or “union.” Wang et al. (2005) draw a distinction between collaboration in the same institution, and regional, national, and international collaboration. The term “team” indicates that genuine collaborative work has been done by coauthors. On the identification of research teams, see also (Calero, Buter, Valdes, & Noyons, 2006). See also Hou, Kretschmer, and Liu (2008).

⁷ This is plainly unethical. On some types of misconduct in publishing, see List, Bailey, Euzent, and Martin (2001).

⁸ In some disciplines where the list of coauthors follows subtle rules (“first author” / “first authors”, last author, other authors, etc.), all coauthors are not equal. We consider here in the set of n coauthors only the real coauthors, that is, in practice, the “first coauthors”. See the discussion below in Section 2.1.

⁹ The quality of the research is important: in scoring systems based on the quality of the journals in which papers are published, the quality of the output is evaluated by the journal's ranking.

index p because we discuss how to credit the coauthors of a same paper. We identify three main methods; (i) it is possible to identify coauthors' relative contributions or (ii) the coauthors self-declare their respective contributions, (iii) no information at all is available and the credit is shared among coauthors equally.

2.1. Identifying the relative input by authors: Is this a solution?

One simple way to shorten discussion about how to attribute merit to each coauthor would be to identify the relative contribution made by each coauthor. This is difficult. In medicine, the rank of coauthors is indicated by the list of coauthors: generally, the names are not sorted by alphabetical order but the first name is the person who has done the greatest share of the work (a Ph.D. student, a PostDoc, etc.). Authorship may even be honorary, particularly in medicine (O'Brien, Baerlocher, Newton, Gautam, & Noble, 2009).¹⁰ Galam (2010) and Prathap (2011) pay particular attention to the rank of authors. Egghe, Rousseau, and Hooydonk (2000) examine the role of different indexes to determine the respective contribution of each author and they show that the result depends largely on the index chosen. On the contrary, in mathematics or in the social sciences or humanities, papers need not be written by large teams (one, two, or three contributors suffice) and the list of coauthors may be in alphabetical order: being the first-named author means nothing. In such instances, and also to evaluate the role of successive authors when being first means something, one might conduct sophisticated analyses of publication networks¹¹ to identify the leader (Yoshikane, Nozawa, & Tsuji, 2006). This is unrealistic in the context of a general scoring system which must evaluate hundreds of scholars at once. Moreover, there is no certainty that focusing on one discipline alone would be sufficient because of interdisciplinary collaboration, which would involve examining thousands of scholars at the same time. On the other hand, for Katz and Martin (1997), who refer to Subramanyam (1983), "... if the level of working together of a number of scientists was below this minimum threshold, they would never appear as coauthors of a publication."

Another method consists in considering that the corresponding author is the leader as in Royle, Coles, Williams, and Evans (2007). However, when contributions are even, choosing the corresponding author as leader might generate a bias; indicating a corresponding author is mandatory and being the corresponding author of a team of equals might mean very little. By contrast, Krapf (2015) considers the age of the coauthors.

2.2. The Utopian solution: self-declared authoring weights

Authors might also state their respective contributions in percentage terms: for a given paper, coauthor a has contributed for a percentage of w_a , coauthor b for w_b , etc. Then, percentages are used to ascertain the merits of each author and we have an objective indication of what the respective contribution of each coauthor i is, in the form of a weight w_i with $\sum_{i=1}^n w_i = 1$:

$$A_i = w_i \text{ for any } i \in \Xi$$

For example, if the weights of the three coauthors 1, 2 and 3 of paper p are respectively 45%, 25%, and 30%, the credit is $A^p = [.45 \ .25 \ .3]$, which means that the three coauthors are respectively credited of 45%, 25%, and 30% of a full paper. The total

credit received by any paper is equal to 1: the rule is neutral with respect to each paper because $\sum_{i=1}^n A_i = 1$.

However, such a rule poses two problems. (i) It is feasible only if all journals of all publishing houses decide at the same time to compel authors to do so. (ii) It is valid for future articles only, not for previously published papers. In short, the procedure is unsatisfactory and Utopian.

Moreover, if a set of coauthors is able to indicate percentages other than $1/n$, it is because all the coauthors really worked on the topic. However, this opens up the way for a game: if the game is cooperative, the result would be a Nash (1951) equilibrium (i.e., for two coauthors, a bilateral monopoly which shares out the common gain equally when information about the respective effort is public¹²), which leads to the next subsection. Actually, treating the question of the self-declaration of the weights w_i would require invoking game theory in a full paper. That would be another story...

2.3. Sharing the credit without information: the "1/n" rule

In the absence of any information about the respective contributions, i.e., if no percentages are indicated, the authors should be considered to be equals: this must be found fair if we apply the Bernoulli-Laplace principle. In other words, because we have no information about the proportions, we should attribute an equal fraction of the total to each one. In the rest of the paper, we consider only the case where all w_i are equal.

We make an assumption: as an editor has no means of detecting fake coauthors, we consider as given the list of coauthors, i.e., n is given by the team. Therefore, the principle is simple. If a paper has been coauthored by n authors, each coauthor is credited equally depending on the number of coauthors n :

$$A_i = 1/n \text{ for any } i \in \Xi \quad (1)$$

Eq. (1) means that each coauthor receives $1/n$ of the points that this paper would have been allocated had it been written by a single author. For example, if a paper has been authored by just one author it counts as one paper for this author; if it has been coauthored by two authors it counts as one-half for each coauthor; by three authors one-third, etc. Hence the name, the "1/n rule". Between zero and $1/n$, i.e., $[0, 1/n]$, any rule is unfair: the whole paper is counted for less than one paper; $1/n$ corresponds to the simple division among all coauthors and unity corresponds to the allotment of the whole paper to each coauthor. We see that we have a margin of maneuver on the segment $[1/n, 1]$. The $1/n$ rule is also neutral with respect to each paper because $\sum_{i=1}^n A_i = n \times \frac{1}{n} = 1$.

However, unlike other systems discussed for personal impact factors by Galam (2010); Hirsch (2009), and Prathap (2011), in which the rank within the list of authors is meaningful, the "1/n rule" treats all authors in the same way, independently of their respective contributions: under the "1/n" formula, each scholar as coauthor is treated equally.

The "1/n" rule is certainly the simplest rule for taking coauthorship into account. Schreiber (2008a, 2008b, 2010) proposes much the same thing in the context of the h index. Such a ranking is computed for every scholar, without considering any other criteria, such as citations, the h -index, and so on; no fractional or adjusted account is made.¹³

On the one hand, multi-authorship may be one way of allowing some researchers to publish who are incapable of publishing alone; on the other hand, coauthorship could be a genuine asset, speeding up publication by allowing a real division of labor among

¹⁰ In physics, the old practice of the laboratory director to add his name to the end of the list of coauthors is now considered unethical. Katz and Martin (1997) underline that the list of coauthors, that is, the multiple signatures on a paper, may not coincide completely with the list of scholars who have actually collaborated on this paper.

¹¹ On networks of coauthorship, see also Cardillo, Scellato, and Latora (2006).

¹² This leads on to the theory of contests; see Tullock (1980).

¹³ Obviously, more sophisticated rules could be chosen, such as $1/n^\alpha$ where $\alpha > 1$, instead of the $1/n$ rule, meaning the benefit of large coauthorship decreases very rapidly. However, justifying them would be difficult.

researchers. One could argue also that if a paper has been written by two or more scholars, it is either because the problem that the paper purports to solve is too big to be handled by a single person, even if the output is only a single paper, or because the paper needs different skills that are rarely found in just one person.

Thus, it could be preferable or even necessary in some academic disciplines to associate multiple authors to produce one paper. In such cases, a multi-authored paper is worth more than a single-authored paper. In a nutshell, the $1/n$ rule is too harsh and discourages multi-authorship even when it cannot be characterized as a publication club. Therefore, the $1/n$ rule should be corrected. This is why we propose to take into account the parallelization of tasks induced by coauthoring, and the productivity gains that it implies, and to reward it.

3. Beyond the $1/n$ rule: parallelization of tasks

3.1. Idea of tasks

Writing an academic paper involves completing a certain number of tasks. What are the tasks in writing an academic paper? They include doing some preliminary thinking about the problem, compiling the bibliography by reading abstracts or perusing a large number of papers, reading a few papers thoroughly, situating the contribution made by the paper with respect to other papers, designing the model, making numerical simulations on the basis of the model or performing the statistical and econometric computations, writing up the results, writing the introduction and the conclusion, etc.

If we consider two tasks i and j , we have here two extreme cases.

Definition 1. (i) A task j is *independent* of a task i if the results of j do not depend on the results of i . The tasks of a couple $\{i, j\}$ that are independent of each other can be performed in parallel. (ii) Tasks that are not independent must be performed serially, one after the other.

To perform tasks in parallel, multi-authorship is obviously necessary. Tasks that can be performed in parallel require either the same skills (e.g., performing clinical tests in two different hospitals) or different skills (e.g., one coauthor specialized in theory and one coauthor specialized in testing).¹⁴ By Ricardo's (1817) theory of comparative advantage, we assume that coauthors practice the horizontal division of labor and specialize in tasks that require differentiated skills. Even if two authors are capable of working on two parallel tasks because they are multi-skilled, it is rational for them to invest their energy in the tasks which they are more productive. In that sense, coauthors are not substitutable.¹⁵ This division of labor is an intelligent way of working (provided that each scholar understands what the others are doing).

On the other hand, in the context of academic publishing and following the philosophy of the $1/n$ rule, we consider that several people working on the same task do not add more than one task.

3.2. Productivity gains generated by parallelization

Two ideas must be introduced at this point: the ideas of cycles and productivity gain.

We do not use the idea of calendar time because the time to write a paper is no better an indicator than the number of pages to determine its importance in a ranking. We all know papers that have been written rapidly but that are excellent and papers that took years and that are poor.¹⁶ Moreover, in the academic world, the idea of calendar time does not make sense because academic time is all fits and starts. Scholars perform many activities in a same week or month. They teach, receive students, meet colleagues, run their department or university, conduct research.¹⁷ Therefore, the calendar time used to write a paper cannot be measured, as underlined by Krapf (2015), that is, "a paper is a paper", whatever the time spent and the number of pages. If we consider the different tasks necessary to write an academic paper, it would be good to be able to define the time necessary to perform the different tasks but the relative time of the tasks that have been necessary to write the paper is difficult to measure objectively. Even it might make sense to say that for one paper, theory represents the main part of the job, or that for another paper, performing trials represents the main effort compared to thinking about theory, it is often impossible to really quantify one task with respect to another. So, we do not determine the total number of hours and days of labor that a paper and the different tasks required by adopting a qualitative approach with respect to these tasks. We attribute the same temporal importance to each task.

Definition 2. A *cycle* is the moment during which a task is performed. Any task is completed during only one cycle but many tasks can be conducted in the same cycle.

It ensues from *specialization* that a coauthor can work on only one parallel task in a same cycle because if an author can work on two or more parallel tasks in the same cycle, then those tasks have been inadequately defined and overlap one another. Consequently

$$n \geq N$$

where N denotes the number of parallel tasks. Therefore, n and N cannot be considered as independent.

Task and cycle would be one-to-one concepts if parallelization was impossible but with parallelization—a crucial idea that we will develop below—it will be possible to conduct two or more tasks in the same cycle.

Definition 3. The *productivity gain* s is the ratio of the number of cycles before introducing parallelism and the number of cycles after introducing parallelism:

$$s = \frac{\eta}{\eta_p} \quad (2)$$

¹⁶ Moreover, we differ here from Krapf's (2015) approach which uses what he terms "human capital" to evaluate the comparative input of two coauthors by a CES function (which implies that both authors' input is perfectly substitutable). Human capital is measured as a discounted function of the number of papers published. Following McDowell (1982) for academic economists, this function depreciates at the rate 13.18 but the function itself is U-shaped. Here, we consider the effort for completing a paper or a task and not the personal input of each author.

¹⁷ Scholars also wait for answers from journal editors. Obviously, the time spent writing a paper may be short compared to the time spent waiting for the answers of the journal to which the paper has been submitted, and so it might be argued that the time is not of importance in academic publishing. However, there is a big difference: in the first case, scholars work, in the second case, they wait. Even if "waiting is harder to bear than fire," according to the Arab proverb, when a scholar waits, he can do other things: thinking, writing another paper, teaching, correcting exams, etc. We would all prefer to produce a paper in collaboration with a colleague in three months than alone in six months, if it is possible, even if we have to wait one year for the answer from the journal: this would enable us to write a second paper in collaboration, or half a paper alone.

¹⁴ Specialized coauthors are able to produce a paper that could be impossible to produce alone. Actually, it could take each one a very long time, perhaps an infinite time, to obtain the skills of the other coauthor. As underlined by Krapf (2015), the paper is of better quality, and the complementarity between coauthors' inputs is maximum, if the difference in age is of ten years or so.

Moreover, working in parallel obviously produces better papers because there is interaction between specialized coauthors. For example, if Theory and Testing can be performed simultaneously, the coauthors will interact and improve what they are doing. The Theory will be better and the Testing will be more appropriate to the Theory for accepting or rejecting its assertions.

¹⁵ Not to be confused with the different idea of substitution of inputs in Krapf (2015). On the other hand, a specialized author cannot be efficient on a paper which requires different unfamiliar skills.

Table 1

Matrix of tasks. Legend: Pr, Preliminary task; Th, Theory; T, Test/econometrics; F, Final task.

	Pr	Th	T	F
Pr				
Th	1			
T	1	0		
F	1	1	1	

where $s \in [1, \infty[$, η and η_p being respectively the number of cycles before and after parallelization. By construction, η is also the total number of tasks. When we have no parallelization, $\eta_p = \eta$ and $s = 1$.

Example 1. Consider a paper with four tasks organized as follows:

- one task for thinking about the paper and preparing the job (preliminary task, denoted Pr),
- one task for writing theory (theory task, denoted Th),
- one task for testing and/or doing econometrics (tests/econometrics task, denoted T),
- one task for synthesis and final writing: (final task, denoted F).

We are able to determine which tasks are dependent, that is, which task must be completed before or after which other task, and which tasks are independent, i.e., can be performed in parallel. In Table 1, a number “1” in cell $\{i, j\}$ indicates that task i should be placed after task j , i.e., in the cycle that follows that of j , a number “-1” indicates that task i should be placed before task j , i.e., in the cycle that is before that of j , and a zero indicates that tasks i and j can be performed in parallel, i.e., in the same cycle.

We have four cases:

- If the paper is single-authored, the author does the whole job and performs the four tasks alone for all four cycles. See the Gantt diagram (Wilson, 2003) in Fig. 2, upper diagram.
- If we have two or more coauthors, but the tasks are dependent, the succession of tasks is the following: Pr, Th, T, F and four cycles are used. In this case, a single author could be sufficient to do the job. See the Gantt diagram in Fig. 2, upper diagram.
- If we have two coauthors and the tasks Th and T are independent, it is better for the coauthors to specialize: one of them should specialize in theory (task Th) and the other one in testing/econometrics (task T). Therefore, the team performs Pr collaboratively in the first cycle; then it performs Th and T in a second cycle; finally, the team performs F collaboratively in a third cycle. As Pr and F could be performed by only a single author, we share the credit between the two coauthors as above but we attribute task Th to one coauthor and task T to the other one. Instead of completing the paper in four cycles, it is now completed in three cycles: this reflects the benefit of specialization/collaboration. The number of cycles goes from $\eta = 4$ to $\eta_p = 3$. So, the productivity gain s generated by parallelism is equal to $4/3$. This corresponds to the functional diagram of Fig. 1 and to the lower diagram of Fig. 2.
- If we have three or more coauthors (i.e., $n > N$) and the tasks Th and T are independent, we consider only two coauthors would be sufficient: the $1/n$ rule will correct that. Again, we proceed as in case (iii).

3.3. Productivity gain in practice

We denote by $N \in \mathbb{N} \setminus \{0\}$ the number of parallel tasks. The number of parallel tasks cannot be higher than the number of tasks. η

being equal to the total number of tasks, we have

$$N \leq \eta \quad (3)$$

Proposition 1. When the paper is composed of some preliminary serial tasks, then of N parallel tasks, and finally of some final serial tasks as in Fig. 1,¹⁸ we have:

$$s(\eta, N) = \frac{\eta}{\eta - N + 1} \quad (4)$$

where $N \in \mathbb{N} \setminus \{0\}$ and $\eta \in \mathbb{N} \setminus \{0\}$ and $s \in [1, \infty[$.

Proof. We have initially η tasks over η cycles. Among the η tasks, we have $\eta - N$ serial tasks that take $\eta - N$ cycles and N parallel tasks that take N cycles before parallelization and 1 cycle after parallelization. There remain $(\eta - N) + 1$ cycles after parallelization. \square

When we have no parallelism, that is, a completely serial paper, $s = 1$, which implies here $N = 1$. See Fig. 2, upper diagram. This is the minimum productivity gain, as proved below.

Proposition 2. The productivity gain is larger or equal to unity, whatever $\eta \in \mathbb{N} \setminus \{0\}$ and $N \in \mathbb{N} \setminus \{0\}$, $N \leq \eta$, are: $s \geq 1$.

Proof. From the minimum of s reached for $s = 1$, which corresponds to $N = 1$, s is an increasing function of N because $\partial s / \partial N = \frac{\eta}{(\eta - N + 1)^2} \geq 0$. s is also a decreasing function of η because $\partial s / \partial \eta = \frac{1 - s}{\eta - N + 1} \leq 0$. As $\eta \in \mathbb{N} \setminus \{0\}$, the minimum of s is reached for $\eta \rightarrow \infty$ and $\lim_{\eta \rightarrow \infty} s = 1$. \square

Remark. $N = \eta$ is a very special case where we have η completely independent tasks, which means that the coauthors work independently, as if there were $N = \eta$ independent papers. Posing $N = \eta$ in (4) gives $s = \eta$.

3.4. Productivity gain and multiple phases

We have implicitly assumed that we invariably had N parallel tasks, while we could have two parallel tasks (e.g., theory and test) at a certain moment of the job and three parallel tasks (e.g., theory, and two types of tests) at another moment. This is why we propose to generalize the above approach by conveniently dividing the effort to produce the paper into *phases*. We will be able to handle more complicated situations and it will be useful to demonstrate a fundamental theorem.

Definition 4. One passes from one phase to another when the number of parallel tasks varies, which includes the case where serial and parallel tasks alternate.

Then, we count in each phase how many parallel or serial tasks are performed: this determines $N_k \leq \eta_k$, the number of parallel tasks in each phase k , η_k being the number of cycles of phase k , knowing that $N_k = 1$ means that the job is performed serially during phase k . In each phase k , we proceed as before to determine the productivity gain s_k attached to it. Then all team productivity gains are aggregated.

Proposition 3. If P denotes the number of phases,

$$s(\eta, N, P) = \frac{\eta}{\eta - N + P} \quad (5)$$

where $N \in \mathbb{N} \setminus \{0, 1\}$, $\eta \in \mathbb{N} \setminus \{0\}$, $P \in \mathbb{N} \setminus \{0\}$ and $s \in [1, \infty[$.

Proof. We have initially η tasks over η cycles. Among the η tasks, we have $\eta - N$ serial tasks that take $\eta - N$ cycles, N parallel tasks

¹⁸ We say that the paper has only one “phase”. In the next section, we examine the case of multiple phases to demonstrate a fundamental theorem, which interestingly allows us to handle resubmissions.

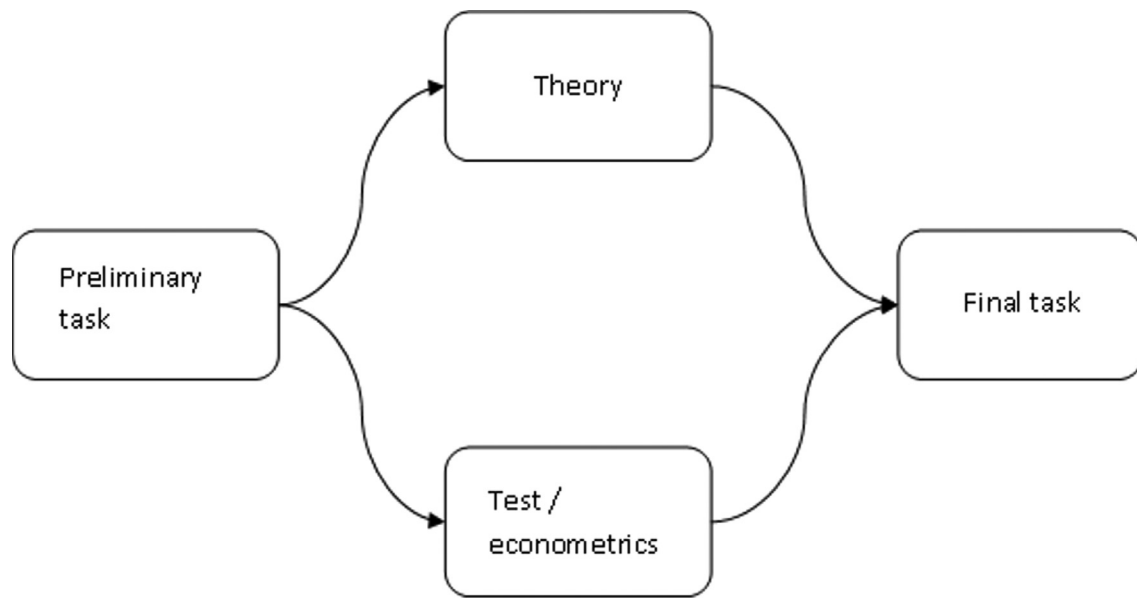


Fig. 1. Paper with two parallel tasks: functional diagram.

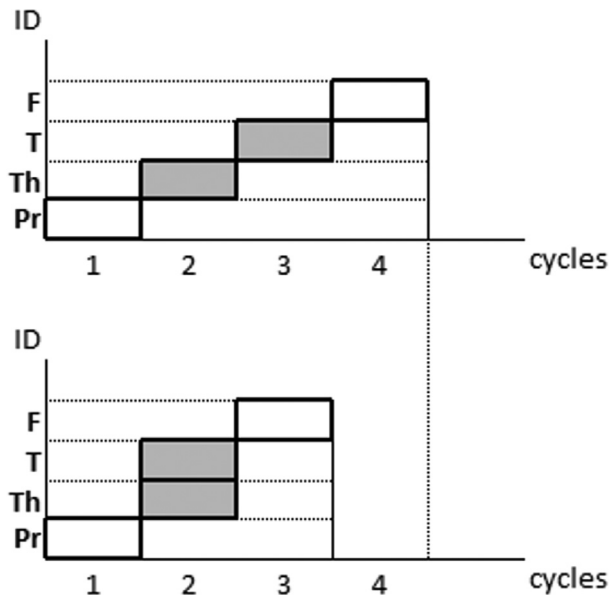


Fig. 2. Paper with four tasks and two parallel tasks: Gantt diagram. Legend: Pr = Preliminary task; Th = Theory; T = Test/econometrics, etc.; F = Final task. Parallel phases are shown in gray.

that take N cycles before parallelization, and P cycles after parallelization. There remain $(\eta - N) + P$ cycles after parallelization. \square

Lemma 1. For a given number of cycles η and a given number of parallel tasks N , $s(\eta, N, P)$ is decreasing with the number of phases P .

Proof. The proof is obvious from (5). \square

We can also handle heterogeneous phases, where the number of cycles changes from one phase to another.

Proposition 4. The total productivity gain is the harmonic mean of the productivity gains of phases, weighted by the number of tasks:

$$s(\{\eta_k\}, \{s_k\}, P) = \frac{\eta}{\sum_{k=1}^P \frac{\eta_k}{s_k}} \quad (6)$$

where η_k is the number of cycles in phase k with $\eta = \sum_{i=1}^P \eta_i$ and where $\eta \in \mathbb{N} \setminus \{0\}$, $\eta_k \in \mathbb{N} \setminus \{0\}$, $P \in \mathbb{N} \setminus \{0\}$, $s_k(\eta_k, N_k) \in [1, \infty]$ and $s(\{\eta_k\}, \{s_k\}, P) \in [1, \infty]$.

Proof. From (4), $s_k = \frac{\eta_k}{\eta_k - N_k + 1}$. Thus,

$$\sum_{k=1}^P \frac{\eta_k}{s_k} = \sum_{k=1}^P \eta_k - N_k + 1 = \eta - N + P$$

\square

However, we have to discuss the number of coauthors: it cannot be lower than the maximum number of tasks to be parallelized, that is,

$$n \geq \max_k N_k \quad (7)$$

We exclude the case where the number of coauthors could vary among the phases to follow the number of parallel tasks: if n coauthors have signed the paper, n coauthors are counted for each phase even if fewer coauthors might be necessary in some phases. In this, the reasoning is similar to that of the homogeneous tasks case.

Example 2. A paper with two resubmissions: we have three heterogeneous phases, as shown by Fig. 3. We have $s_1 = 2$, $s_2 = 4/3$ and $s_3 = 5/3$. In total, we have a productivity gain of $s = 5/3$.

4. Parallelization bonus and credit

4.1. The reward

We now propose to reward parallelization because it corresponds to an intelligent and efficient way of using the resources that coauthors have at their disposal in order to produce better papers. We will correct each coauthor i 's contribution (measured by $1/n$) by the productivity gain s considered as a *parallelization bonus* to increase what is attributed to each coauthor of a multi-authored manuscript. In doing so, we reward true multi-authorship because it corresponds to a real advantage when it is compared to a simple addition of n coauthors who work serially on the same paper, and it is the sign that coauthors have better skills (e.g., they are each able to work on theory and testing). However, the authors will only be rewarded, not punished: the parallelization bonus must not be lower than unity, i.e., $s \geq 1$.

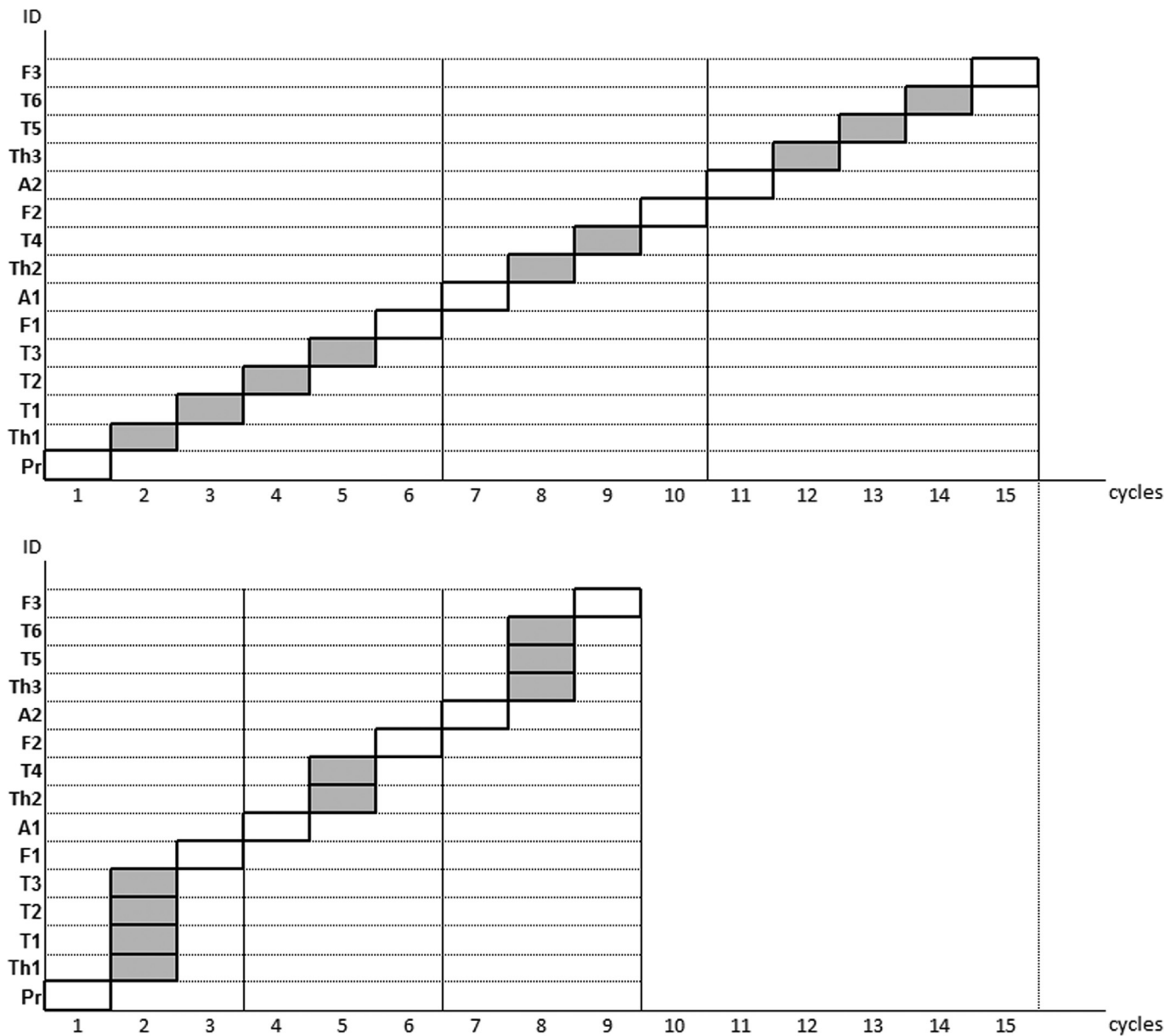


Fig. 3. Paper with resubmission, three heterogeneous phases: Gantt diagram. Legend: Pr = preliminary task; Th1 = theory 1; T1 = test/econometrics 1; T2 = test/econometrics 2; T3 = test, econometrics 3; F1 = synthesis, final writing 1; A1 = analysis of reports; Th2 = theory 2; T4 = test/econometrics 4; F2 = synthesis, final writing 2; A2 = analysis of reports; Th3 = theory 3; T5 = test/econometrics 5; T6 = test/econometrics 6; F3 = synthesis, final writing 3. Parallel phases are shown in gray.

Now, we can produce the new credit rule. To stay on the case of the $1/n$ rule (1), we define

$$A_i = s/n \text{ for any } i \in \Xi \quad (8)$$

with respect to s , s being given by (2), (4), (5), or (6).¹⁹

Example 3. If we return to the data of Example 1, each coauthor has contributed to half of the productivity gain of $s(2) = 4/3$, which is a bonus. If we have no information about each coauthor's respective contribution, it will be divided by $n = 2$, that is, $2/3$, we find $A_i = 2/3$ for $i = 1, 2$. The paper is counted for $2/3$ to each coauthor instead of 1 under the usual system and $1/2$ by the $1/n$ rule. The minimum number of coauthors is two. In

Example 2 where $s = 5/3$, we have necessarily at least four coauthors and the allocation for each coauthor is $A_i = 5/12$.

The total allocation attributed to a paper is greater than or equal to 1: the new rule $A(s)$ is not neutral but is favorable to the team with respect to each paper because

$$\sum_{i=1}^n A_i = s \geq 1$$

This should be compared to the situation where no rule at all is applied: because each coauthor is awarded 100% of the paper, the whole paper is awarded n , which is too much.

Example 4. In Example 1, $A_i = 2/3$ for $i = 1, 2$ and $\sum_{i=1}^2 A_i = 4/3$ obviously.

Remark. When $n = 1$, $N = 1$, $s = 1$ and thus $A_i = 1$: the unique author receives the whole award, as expected.

¹⁹ We have simplified the notations here. Actually it should be: $s(\{\eta_k\}, \{N_k\}, P)$ and $A_i(\{\eta_k\}, \{N_k\}, P)$.

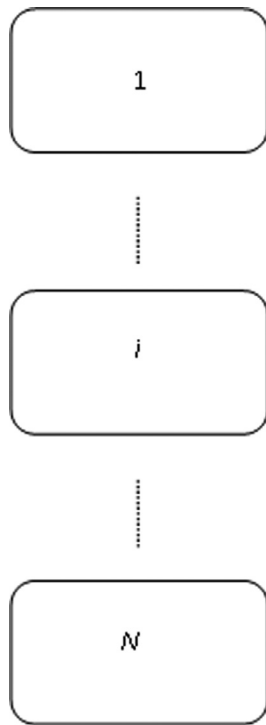


Fig. 4. Paper with only N parallel tasks. Functional diagram.

4.2. A maximum limiting case

We have posited that $N \leq n$ because of specialization. When we have more coauthors than parallel tasks, the $1/n$ rule comes to “punish” them by dividing the credit between them the $n - N$ coauthors can be considered surplus to requirements. Cheating occurs here: the team may declare a higher parallelization than really occurred. Fortunately, we will show now that there is a limit to cheating.

Is a full parallelization possible? Certainly not: we would have N completely independent papers (see Fig. 4). Similarly, one preliminary task and N parallel tasks (see Fig. 5) is an impossible configuration: writing the paper would never end. N parallel tasks and one final task is also impossible (see Fig. 6): writing the paper would never begin. Therefore, we should have at least one preliminary task, N tasks that can be performed in parallel, and one final task, as described by Fig. 7. We will show now that this is the limiting case in a fundamental theorem.

Definition 5. $s^L(N)$ is the parallelization bonus that corresponds to the particular case of one phase, with one preliminary task, N tasks performed in parallel, and one final task.

Theorem 1. If we assume that each team tries to maximize its bonus, the particular case of one preliminary task, N tasks performed in parallel, and one final task, is a Pareto maximum. Hence the name limiting case.

We are in the case of Figs. 7 or 1.

Proof. From Lemma 1, $s(\eta, N, P)$ is decreasing with P . So, $s(\eta, N, 1)$ is the maximum of the $s(\eta, N, P)$. Moreover, we have $\eta - N$ serial tasks. As $s(\eta, N, P)$ is increasing when $\eta - N$ decreases,²⁰ the maximum of $s(\eta, N, 1)$ is found for $\eta - N$ minimum, that is $\eta - N = 2$, which corresponds to $s^L(N)$. Thus, $s^L(N)$ is the maximum (it is impossible to go beyond it). It is a Pareto equilibrium in the sense

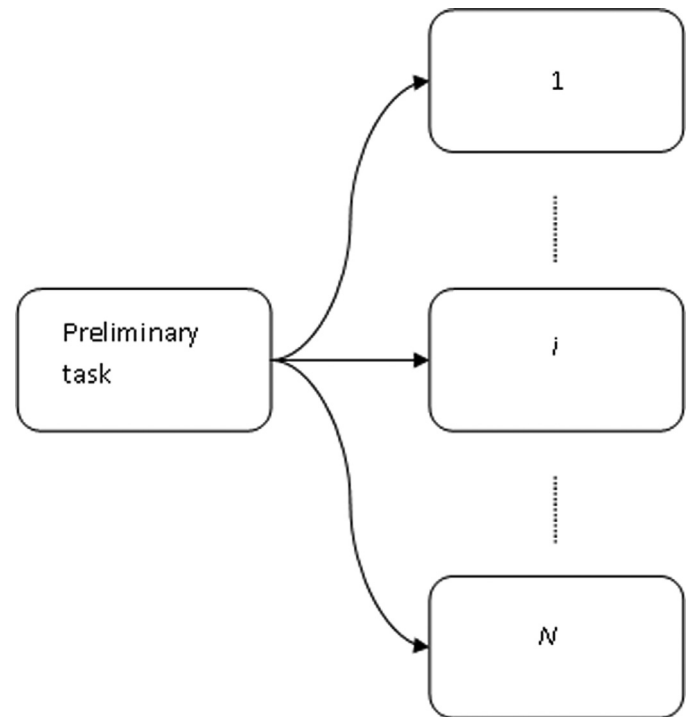


Fig. 5. Paper with one preliminary task and N parallel tasks. Functional diagram.

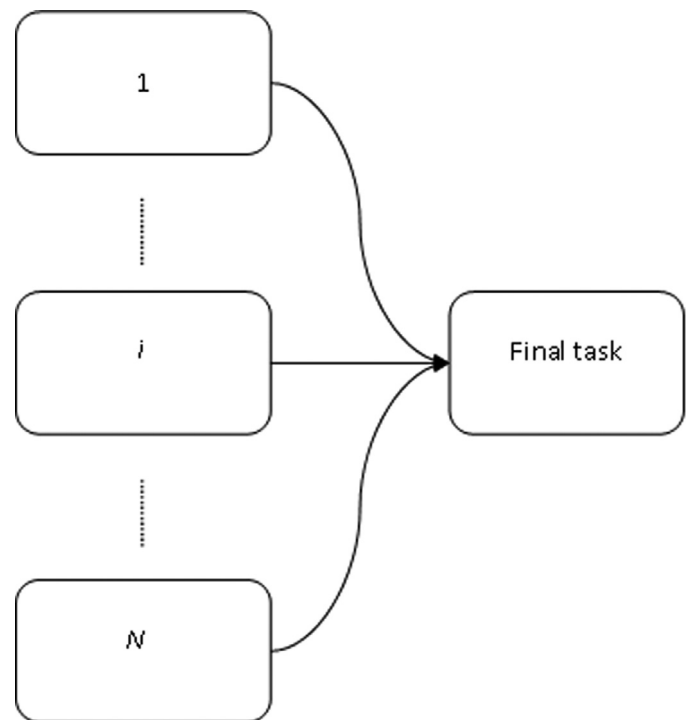


Fig. 6. Paper with N parallel tasks and one final task. Functional diagram.

that if the team attempts to deviate from this maximum by self-declaring some other form of organization of labor (where possible), this will penalize at least one team member. \square

In Theorem 1 we have only one phase in the limiting case. So, it ensues from (4) that:

$$s^L(N) = \frac{N+2}{3} \quad (9)$$

²⁰ If we write $\eta - N = x$, $s(\eta, N, P) = \frac{x+N}{x+1}$ and $\frac{d}{dx} \frac{x+N}{x+1} = \frac{1-N}{(x+1)^2} < 0$ for $N > 1$.

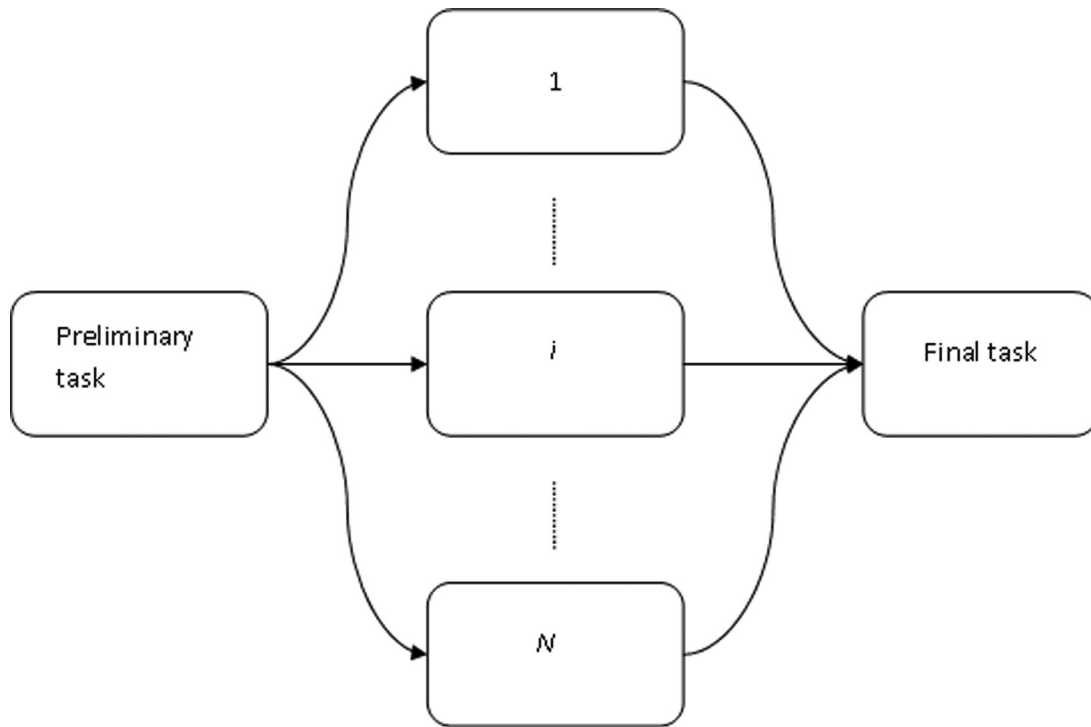


Fig. 7. Paper with one preliminary task, N parallel tasks, and one final task. Functional diagram.

We see that $s^L(N) \xrightarrow{N \rightarrow \infty} \infty$ and that $s^L(N)$ is simply linear. To $s^L(N)$ corresponds

$$A_i^L = \frac{N+2}{3n} \text{ with } N \leq n \quad (10)$$

When the number of parallel tasks is maximum and equal to the number of coauthors, i.e., $N = n$, the maximum maximorum credit is

$$A_i^{L\max} = \frac{n+2}{3n} \quad (11)$$

It varies between $2/3$ for two coauthors and $1/3$ for an infinite number of coauthors (from (9), which is a decreasing function as $\frac{dA_i^{L\max}}{dn} = -\frac{2}{3n^2} < 0$). Fig. 8 illustrates the credit $A_i^{L\max}$ and compares it to the $1/n$ rule.

5. Conclusion

Universities that are recruiting faculty or that must rank their researchers for promoting them, have to attribute the fair merit to each scholar. It is not a question of indexes (such as the h-index, etc.) but of sharing the credit between coauthors of multi-authored papers. A multi-authored paper is generally counted today as one paper for each coauthor when no information about each author's contribution is available, meaning that an n -coauthored paper counts for n papers. This is too generous and we term it “feeding the multitude”. A contrasting approach consists in allocating the merits by applying the “ $1/n$ rule” when no information is available,²¹ thereby dividing the credit given to a complete paper by the number of coauthors. This is too harsh. Even if this discourages what we term *publication club*, the credit allocated to each

coauthor tends to zero in large teams (commonly found in some experimental disciplines).²²

This is why we propose a completely new approach. We take into account the productivity gains of parallelization by introducing a parallelization bonus that rewards cooperation—i.e., the possibility of parallel work—by multiplying the credit allocated to each coauthor.

Correcting the $1/n$ law by introducing the idea of team bonus encourages scholars to cooperate where it is necessary and justified. Nevertheless, it also encourages coauthors to be involved in many papers where they always perform the same type of tasks. However, it depends on which scientific domain is considered. The criticism must be rejected in disciplines where extensive research is necessarily conducted by large teams. The criticism should be accepted in all domains where theory predominates or where it is common practice to publish alone (we have all heard it said of scholars that “they have to prove their worth”). The situation is more contrasted when the approach can be partially experimental or when a range of skills may be useful for writing a paper. Thus, the degree of parallelization may vary from one discipline to another but as the intra-discipline variability may be very large it varies also from one paper to another. Therefore, the true degree of parallelization cannot be determined exogenously, which would be artificial. So, in order to determine the parallelization bonus, one could propose that each team of coauthors indicates, when the paper is submitted to a journal, how the labor was organized to produce the paper. However, this implies that they collect and provide a lot of information about the way they worked and is valid only for future papers.

Yet, even if the laboratory notebook (when it exists) could help to reveal the truth, the coauthors may cheat by exaggerating the

²¹ Or by applying self-declared percentages of coauthors' contributions, but this could be Utopian.

²² For example, for the 5154 coauthors of the Aad and ATLAS Collaboration, CMS Collaboration (2015) paper, the $1/n$ rule allocates $1/5154 \approx 0.02\%$ of a complete paper to each coauthor, a ridiculously low reward.

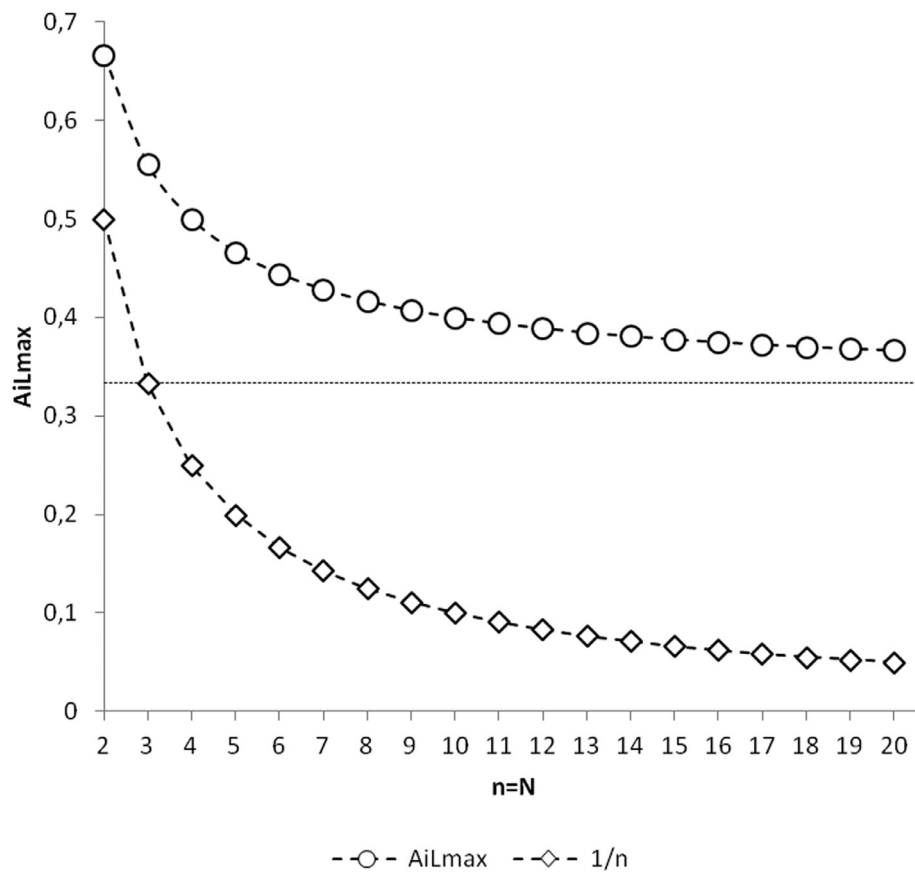


Fig. 8. Limiting credit A_i^{Lmax} and $1/n$ for some values of $n = N$. n is an integer.

degree of parallelism and adding parallel tasks. Obviously, degree of parallelism and team organization are linked. So, after showing that we cannot have more parallel tasks than co-authors because of specialization, that is, $N \leq n$ (n being the number of coauthors and N the number of parallel tasks),²³ we show that the limiting case (which has one preliminary task, N tasks that can be performed in parallel, and one final task), is a Pareto maximum with a credit to each coauthor i of $A_i^L = (N+2)/3n$ of a paper written by a single author. So, even if coauthors exaggerate by declaring too many parallel tasks, they are limited by this maximum. In short, whatever the true organization of the tasks and their parallelization, and even if coauthors try to cheat, we cannot give more to each coauthor. Obviously, it could be difficult to apply the $(N+2)/3n$ rule for past papers or without the agreement of publishing houses.

Fortunately, the maximum maximum credit is reached when the number of parallel tasks is itself maximum, that is, equal to the number of coauthors, i.e., $N = n$. So, we attribute to each coauthor i a credit of $A_i^{Lmax} = (n+2)/3n$ of a paper written by a single author. When this credit is attributed, coauthors do not want to cheat about parallelization. This is $2/3$ of a paper to each of two coauthors, $5/9$ to each of three coauthors, etc., up to $1/3$ to each of a very large number of coauthors: this is much more favorable to coauthors than $1/2$, $1/3$ of a paper, etc., up to zero, distributed by the $1/n$ rule. This “maximum parallelization credit” rule can be applied to future papers as well as past papers²⁴ or without any agreement of publishing houses, even when coauthors do not, or cannot,

communicate how they were organized, or when the journal does not wish to require such information. *We only need to know the number of coauthors.* For example, for the 5154 coauthors of Aad and ATLAS Collaboration, CMS Collaboration (2015), we are able to credit each coauthor with one-third of a paper written by a single author. This might seem too generous but it is a fair reward as demonstrated above. It is largely above the 0.02% allocated by the $1/n$ rule but it is clearly below the unfair credit of one full paper per coauthor.

We hope that the publication of the present article would generate a progressive change in attitudes to the necessity of understanding how each coauthored paper is produced in order to go beyond the subtle but unclear and shifting rules that we have in some disciplines. It could largely help interdisciplinarity progress. This new approach is feasible, and fair and it credits genuine co-operation in academic publishing. It could give rise to a new way of comparing scholars, especially for recruitment and promotion. “Lifting the hood” and looking inside the “machine” to see how the job of writing papers is done, is new. It could open the door to future developments and create a new branch of bibliometrics. We hope that this new rule will encourage researches on how academic papers are produced by taking into account the organization of the tasks that are necessary to write a paper.

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²³ For example, a team of three coauthors may not claim four parallel tasks.

²⁴ Most bibliometric indicators (impact factor, h-index (Hirsch, 2005), etc.) have been applied *ex post*, on the papers published before they were devised.

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