1 SUMMARY OF RELATED WORK AND OUR FINDINGS

Table 1. Prior studies comparing paid and volunteer open source developers

Study	Method	Findings
Hars and Ou 2002 [4]	Web survey, n=81 (77 male, 95%)	Almost half of respondents were professional programmers; 16% of respondents were paid for their open source work. Stronger correlation with efforts in self-marketing and selling products, and negative correlations for peer recognition and community identification, than hobby and salaried programmers.
Hertel et al. 2003 [5]	Web survey among Linux kernel developers, n=141 (135 male, 96%).	20% of developers were paid regularly for their work on Linux, 23% were paid sometimes; the remaining 57% received no salary. Paid and non-paid developers spend about the same amount of spare time on Linux development. 59% worked with others on a given Linux module in 'virtual teams' (average size of 12, range 2-50).
Lakhani and Wolf 2005 [6]	Web survey, n=684 from 287 projects (667 male, 97.5%)	87% of respondents received no *direct* payments. 55% contributed during work time: 38% with supervisor awareness, and 17% without. 40% were paid either directly or indirectly (i.e., with supervisor awareness). Paid contributors were strongly motivated by work-related user needs; volunteers were more likely to improve their skills or needs for non-work purposes.
Riehle et al. 2014 [10]	Sample study based on commit data from Linux kernel and Ohloh projects	Ca. 50% of contributions to open source projects are made during office hours, defined as 9 am-5 pm on Monday-Friday. Paid developers are defined as those who conducted 95% of their commits during office hours; volunteers are those who performed 95% of their commits during spare time (i.e., outside office hours). Over 23% of Linux authors are paid (n=1,807), and over 11% of committers (n=37) to Linux are paid. Ca. 18% of committers to Ohloh projects (n=8,244) are paid.
De Blanc et al. 2017 [1]; O'Neil et al. 2021 [9]	Web survey, n=1,479 (1,405 male, 95%)	170 respondents indicated to get paid for their contributions; however, only 79 indicated to acknowledge the organization paying them.
Dias et al. 2020 [2]	Sample study of 11,885 pull requests; 5,143 by 94 employees, and 6,742 by 2,962 volunteers from five projects owned by GitHub: atom, electron, hubot, git-lfs, and linguist	Paid developers are defined as those who have the 'site_admin' flag set (i.e., GitHub employees). 48% of contributions to linguist made by volunteers were to add new features. For atom, electron, git-lfs, most work was reengineering. 25% of contributions to atom, electron, git-lfs made by employees were categorized as 'management'. Volunteers are more active on weekends. A significant proportion of volunteer contributions are made during office hours.
O'Neil et al. 2021 [8]	Sample study of 135 GitHub repositories, 2.8m+ commits	Contributions from firm employees dip during the weekend in contrast to those from volunteers. Overall, contributions from firm employees are dominant.

Table 2. Summary of findings

	RQ1: Do paid developers and volunteers differ in their contribution behavior to the Rust project?			RQ2: Do paid developers and volunteers collaborate?	RQ3: Does being paid or not affect the possibility of a Rust developer becoming a LTC to the Rust project?
Contributor group	H1. Paid developers contribute more frequently than volunteers.	H2. Paid developers contribute larger chunks of code in commits.	H3. Paid developers are more likely to contribute features than volunteers.	H4. Paid developers tend to collaborate less with volunteers.	H5. Paid developers are less likely to become long-term contributors.
One-time	NA	**Supported**	**Supported**	Not supported	Not supported
Periphery	Not supported	Not supported	**Supported**	Not supported	Not supported
Core	**Supported**	Not supported	Not supported	Not supported	Not supported
	RQ4: How do volunteers perceive the participation of paid developers in the Rust project?				
	33 agreed; 10 were neutral; 5 disagreed.	21 agreed; 21 were neutral; 6 disagreed.	14 agreed; 22 were neutral; 12 disagreed.	12 agreed; 10 were neutral; 26 disagreed.	7 agreed; 26 were neutral; 15 disagreed.
	RQ5: What emotions will arise when Rust volunteers are hired by companies to work on Rust?				
Emotion	Overall	Reddit	Hacker News	X	
Anger	2%	2%	2%	1%	
Disgust	7%	12%	8%	-	
Fear	1%	1%	1%	-	
Sadness	3%	4%	1%	4%	
Neutral	56%	59%	76%	26%	
Joy	24%	18%	4%	60%	
Surprise	7%	5%	8%	8%	

2 DIALOGUE-BASED COLLABORATION BETWEEN PAID DEVELOPERS AND VOLUNTEERS

To validate the findings of RQ2, we further conducted comparison experiments using a dialogue-based collaboration metric derived from pull request (PR) interactions, where two developers are considered to have collaborated if they both commented on the same PR. We collected 582,795 review comments from the Rust ecosystem until December 16, 2021 (to keep consistency with the time scope of our commit data). Since not all PR commenters disclose their email addresses in their GitHub profiles, we identified paid developers by matching them with those already classified in our commit dataset. This matching process successfully covered approximately 76.9% of PR comments.

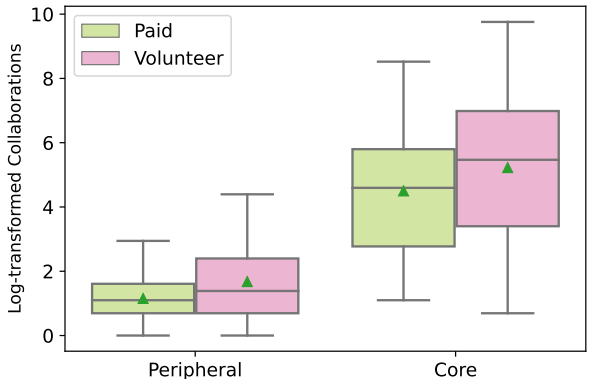

Fig. 1. Paid developers' collaborations with other paid developers (green box) and volunteers (pink box) across two groups: peripheral paid developers and core paid developers.

Table 3. Comparison of collaboration patterns at macro and micro levels

Group	Macro: Wilcoxon signed-rank test	Micro: permutation-based null model
Core	p-value = 1.8e−08; statistic = 18.5	Z-score = −0.52; p-value = 0.04
Peripheral	p-value = 2.6e−09; statistic = 435.5	Z-score = −3.12; p-value = 0.01

As shown in Table 3 and Figure 1, although both core and peripheral paid developers show higher collaboration with volunteers at the macro level, as indicated by the significant Wilcoxon signed-rank test results (all $p < 0.001$), the micro-level permutation-based analysis reveals a different pattern. Specifically, the Z-scores for both groups are negative (Core: $Z = -0.52$, $p = 0.04$; Peripheral: $Z = -3.12$, $p = 0.01$), suggesting that their actual collaboration with volunteers is weaker than expected given the overall distribution of paid and volunteer developers in the Rust community. The results based on PR comments were consistent with the findings of RQ2, supporting the robustness of our approach.

3 VALIDATION ON NEW DATA

H1: Paid developers contribute more frequently than volunteers.

We compare the contribution behavior of paid and voluntary developers in the periphery group on contribution frequency, using data from December 17, 2021 to June 30, 2025. The left pair of

boxplots in Figure 2 shows that the distribution of contribution frequency of volunteers and paid developers is similar. Specifically, the median frequency for both peripheral volunteers and paid developers is 1 commit per month. A Mann–Whitney U test [7] indicates there is no statistically significant difference (p = .98). Thus, *H1* is not supported for developers in the periphery, which is consistent with what we found in Rust before December 17, 2021. The right paired box plots in Figure 2 present the contribution frequency distribution of core voluntary and paid developers. The median number of commits per month is 3.4 for volunteers and 2.4 for paid developers. However, a Mann–Whitney U test shows that the difference between the two groups is also not statistically significant (adjusted p = .10). The reason may lie in the increasing maturity of Rust, which can slow down the contribution speed of developers.

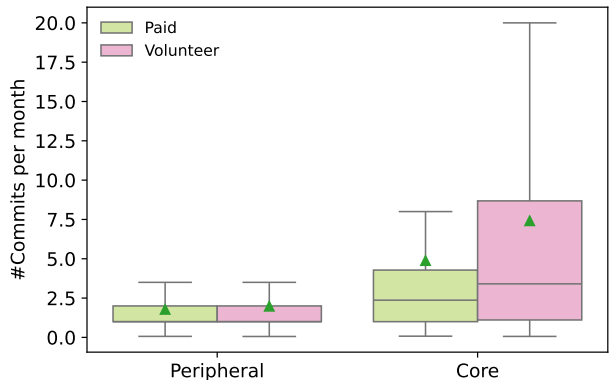

Fig. 2. Contribution frequency distributions of paid developers and volunteers in the two groups.

H2: Paid developers contribute larger chunks of code in commits.

The first paired box plots in Figure 3 show the LOC distribution of peripheral volunteers and paid developers. Specifically, the median LOC of commits contributed is 14 for volunteers, and 16.5 for paid developers in the peripheral group. A Mann–Whitney U test to assess the significance of the difference between peripheral paid developers and volunteers in terms of the LOC distributions shows a statistically significant difference (*adjusted* p = .006), although with a small effect size[1] of .09. The results indicate that peripheral paid developers tend to contribute a bit larger code changes to OSS projects than peripheral volunteers, in support of *H2*. The second pair of box plots in Figure 3 shows the LOC distributions of paid and volunteer developers in the core group. A Mann–Whitney U test confirms that no statistically significant difference exists between the two groups (p = .82), and the effect size is negligible (r = .02). These findings suggest that, for core developers, whether one is paid or volunteering does not substantially affect the size of code contributions, thus providing no support for ***H2***.

H3: Paid developers are more likely to contribute features than volunteers.

Figure 4 shows the distribution of task-type ratios for paid and volunteer developers in the peripheral group. Peripheral paid developers tend to perform a higher proportion of feature-related (adaptive) commits, with a median of 0.17, compared to 0.00 for volunteers. A Mann–Whitney U test indicates that this difference is statistically significant (p = .034), though the effect size is small (r = .07). For

[1]effect size ≥ 0.1 (small) ≥ 0.3 (medium), and ≥ 0.5 (large) [3].

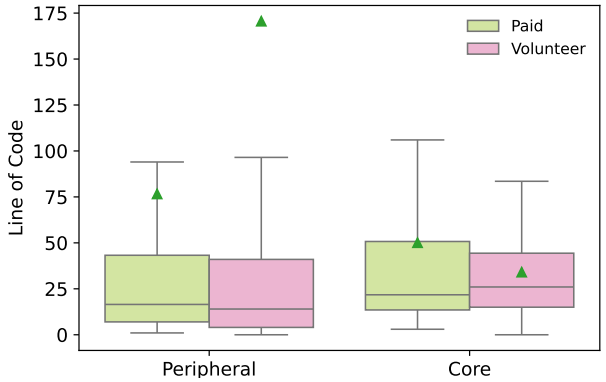

Fig. 3. LOC distributions of paid developers and volunteers in the two groups.

perfective tasks, both groups show similar behavior — the median proportion of perfective commits is 0.64 for volunteers and 0.60 for paid developers, with no significant difference (p = .60). These findings suggest that while both groups spend most of their effort improving existing code, paid developers are slightly more likely to engage in feature development, offering partial support for ***H3***.

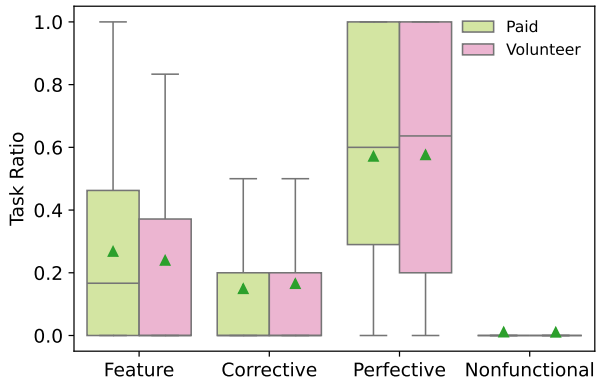

Fig. 4. Task distributions of peripheral developers.

We also compare the task-type distributions of core paid and volunteer developers, as shown in Figure 5. For both groups, perfective commits are the most common, followed by feature and corrective commits, while non-functional changes account for the smallest proportion. A Mann–Whitney U test on the distribution of feature-related tasks shows no significant difference between the two groups (p = .62, r = .04). The medians are also close, 0.22 for volunteers and 0.25 for paid developers. These results suggest that core paid and volunteer developers exhibit similar task preferences, providing no support for ***H3*** in the core group.

H4: Paid developers tend to collaborate less with volunteers.

We utilize social network analysis to explore whether being paid affects development collaboration in Rust between December 17, 2021 and June 30, 2025. Similarly, we divide paid developers into

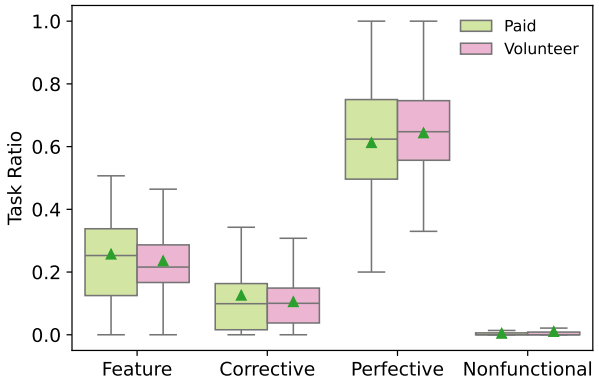

Fig. 5. Task distributions of core developers.

peripheral and core groups and then compare their collaboration likelihood with volunteers or paid developers in both macro and micro perspectives.

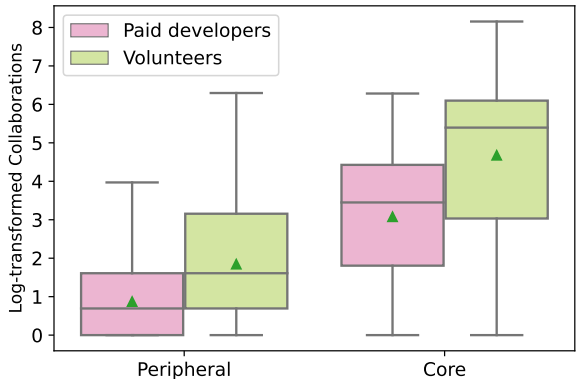

Fig. 6. Paid developers' collaborations with other paid developers (green box) and volunteers (pink box) across two groups: peripheral paid developers and core paid developers.

Figure 6 shows the collaboration distribution of paid developers with volunteers and other paid developers, organized by peripheral and core paid developers. Across both groups, paid developers tend to collaborate more with volunteers.

At the macro level, we compared the differences between the collaboration of the two groups' paid developers with volunteers and paid developers using the Wilcoxon signed-rank test [11]. The results show that both groups of paid developers are more inclined to collaborate with volunteers when compared with paid developers (all p-values < 0.0005). This finding is consistent with what we observed based on Rust's development data before December 17, 2021. We further performed a permutation-based analysis at the micro level. However, at this level, we do not observe a statistically significant collaboration preference among paid developers toward other paid developers. Specifically, for core paid developers, the observed paid-to-volunteer collaboration ratio (0.91) is slightly higher than the randomized expectation (0.85), but the difference is not significant ($Z = 1.17$, one-sided $p = 0.91$). Similarly, peripheral paid developers exhibit an almost identical pattern, with an observed ratio (0.86) close to the randomized mean (0.84) and a non-significant deviation

Table 4. Results of the logistic regression model (n=1,654)

Variable	Coeff.	Std.Err	z	P value)
(Intercept)	−3.95	0.29	−13.44	0.00
Being Paid	0.62	0.19	3.32	0.00
Contribution Frequency	0.65	0.10	6.40	0.00
LOC	0.27	0.05	5.15	0.00
Corrective	−0.42	0.38	−1.10	0.27
Perfective	0.20	0.21	0.94	0.35
Nonfunctional	0.57	0.80	0.71	0.48

* LLR p-value = 8.961e-19; Pseudo R-square = 0.08.

($Z = 0.36$, one-sided $p = 0.61$). These results suggest that, after controlling for network structure through randomization, neither core nor peripheral paid developers show a strong tendency to collaborate preferentially with paid peers.

H5: Paid developers are less likely to become long-term contributors.

We considered the same set of factors and conducted a regression model on developers who contributed commits to Rust between December 17, 2021 and June 30, 2025. The regression is:

$$\text{isLTC} \sim \textit{Being Paid} + \textit{Contribution Frequency} + \textit{LOC} + \textit{Task Type}$$

Table 4 shows the results of the fitted model. The positive coefficient and p-value of *Being Paid* indicate that paid developers tend to have a higher probability of becoming long-term contributors when compared with volunteers, which is consistent with what we observed based on Rust's development data before December 17, 2021.

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