Peer Learning in Teams and Work Performance:
Evidence from a Randomized Field Experiment

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Abstract: A novel field experiment shows that learning activities in pairs with a greater spread in abilities lead to better individual work performance, relative to those in pairs with similar abilities. The positive effect of the former is not limited to their performance in peer learning material, but it also spills over to their performance in other areas. The underlying improvement comes from the increased performance of those whose achievements were weak prior to peer learning. This implies that exogenously determining learning partners with different abilities helps improve productivity through knowledge sharing and potential peer effects.

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1. Introduction

Situations in which peers interact with each other to improve performance, while aiming to achieve individual goals, are ubiquitous whether in schools, daily lives, or the workplace. A key to achieving a mutually beneficial outcome is successful collaboration among peers. Benefits from peer interactions may be strong when they have heterogeneous abilities and skills if the less endowed interact with and learn from the highly endowed, because the former has larger room for improvement. A dilemma, nevertheless, exists since peer learning interactions may not be cost-free and benefits may be small for the highly endowed individuals.

Prior research suggests that people's individual performance, whether work-related or academic, are affected by other members in their peer groups due to peer pressure and learning through social interactions (e.g., Katz *et al.*, 2001; Sacerdote, 2001; Falk and Ichino, 2006; Mas and Moretti, 2009). For example, peer interactions and learning are powerful practices in firms and organizations (e.g., Ichniowski *et al.*, 1997; Hamilton *et al.*, 2003). However, how peer groups should be formed is not straightforward. First, peer interactions are known to lead to better overall work performance in a group with heterogeneous rather than homogeneous abilities and skills[1] under individual-based remunerations (i.e., each member is evaluated based on their own individual performance), even though the average abilities and skills are similar for the two types of groups (e.g., Carrell *et al.*, 2009; Lyle, 2009; Duflo *et al.*, 2011; Feld and Zölitz, 2017). The superiority of group heterogeneity is driven by high-ability (-achieving) members. They are able to and tend to form subgroups with like-minded high achievers, thereby leading to a further improvement of their performances. In contrast, low-ability (-achieving) members suffer, although, on average, overall performance in the group is better thanks to the strong improvement of the high types. It is therefore difficult to judge the efficacy of heterogeneity normatively. Second, groups with a greater spread in abilities are likewise known to have an advantage under group incentives, that is, when members are evaluated based on their group performance. The underlying mechanism is, however, different, and is the so-called mutual learning hypothesis: under group incentives, more able workers not only impose norms for the sake of other members, but they also teach less able workers (e.g., Ichniowski *et al.*, 1997; Hamilton *et al.*, 2003). Hence, the finding from the second branch of the literature implies that a way to form a socially-desirable peer group under individual-based remunerations may be to have a sufficiently small peer group with a greater spread in abilities, thereby preventing sub-groups from endogenously emerging and, at the same time ensuring a pairing between more able

[1] The former (latter) group is also called a "heterogeneous" ("homogeneous") group, hereafter, in the paper.

and less able workers. Such pairing may result in a performance improvement of the less able through effective peer learning. This paper experimentally manipulates interim achievement differences in pairs and then studies how the intervention affects individual work performance.

While it is unclear how the mutual learning hypothesis extends to the case of a small group under individual incentives, pairing a more able worker with a less able worker for peer learning has an advantage at least from a theoretical perspective. For example, experimental literature suggests that people have social image concerns and other-regarding preferences (e.g., Ariely *et al.*, 2009; Shang and Croson, 2009). Pairing with a high-ability worker may give the low-ability worker a particular incentive to work hard to avoid incurring disutility from social effects, such as shame and harming their social image (e.g., Bénabou and Tirole, 2006 and 2011; Bowles and Gintis, 2015). Such a pairing may also change reference points of the less able workers if they have poor work attitudes and are over-optimistic about their own performance (e.g., Abeler *et al.*, 2011; Svenson, 1981). High-ability workers may also try helping low-ability ones from inequality aversion if they are required to interact with each other (e.g., Fehr and Schmidt, 1999). A possible concern is, however, a perverse reaction by high-ability workers: those who are forcibly matched with low-ability ones contrary to their preferences may not contribute their best efforts in peer learning activities (e.g., Kamei and Markussen, forthcoming).

This paper provides clean evidence from a randomized field experiment in a classroom that pairing individuals with a large achievement difference, rather than with similar achievement levels, in peer learning activities leads to better overall performance on average. All first-year undergraduate students in accounting and finance took a compulsory first-year introductory course in economics in Durham University during the 2019/20 academic year. This was a full-year course which began in the first term of the academic year. Students learned microeconomics in the first term, and macroeconomics in the second term. The students' performances were evaluated solely based on their own marks in a written examination which took place at the end of the academic year.

The students' learning activities were composed of attendance in lectures, engagement in bi-weekly mandatory seminars (whose size was 15 to 20 students), two formal written assignments (one for each term), and two peer review assessment activities (one for each team). In the peer review assessment activities, each student was paired with another in their respective seminar group. They independently attempted a problem set, after which they critically assessed their partner's solutions and then discussed the problem set in pairs by holding a meeting. Pair partners were changed between terms 1 and 2. An intervention was made for the peer review activities in term 2: while each student was randomly assigned their pair partner in half of the seminar groups (treatment condition), pairs were formed so that their interim class performances were similar to each other in the other half of the seminar groups (control condition). Thus, pairs in the treatment condition had a greater variation in interim achievement levels between pair mates, relative to those in the control treatment. Partner assignment was random in all seminar groups for term 1.

The exam marks show that students were higher-achieving on average in the treatment than in the control condition. This underscores the effectiveness of having a pair with a greater spread in prior performance for peer learning in organizations. A close look at the data reveals that the worse performers improved academic performance significantly more than their matched better performers in pairs belonging to the treatment condition. This suggests that consistent with the mutual learning hypothesis, exogenously determining learning partners with different abilities helps improve productivity through knowledge sharing and positive peer effects. Further, interestingly, the students in the treatment groups showed better understanding of even the term 1 material in the examination, suggesting that their peer learning experiences in macroeconomics spilled over to their understanding of microeconomics. This may mean that worse performers improved study habits when revisiting the term 1 material for the exam. Such productivity spillovers within individuals further imply the importance of devising an effective pairing procedure.

The rest of the paper proceeds as follows: Section 2 describes the related literature, and then Section 3 discusses the background, the experimental design, and the procedure. Section 4 briefly describes hypotheses based on behavioral models and 5 presents the results. Section 6 provides discussion and concludes.

2. Related Literature

This study is closely related to three branches of the literature in labor, organizational and personnel economics, experimental economics, and economic education: (a) peer interactions in heterogeneous teams, (b) peer pressure and productivity, and (c) mutual learning theory. While the literature in (a) seem to suggest that teams with homogeneous rather than heterogeneous abilities and skills lead to better performance, the literature in (b) and (c) suggests the opposite. However, prior research, on balance, suggests the superiority of heterogeneous teams.

2.1. Peer Interactions in Heterogeneous Setups

A key aspect of teamwork in teams is how students share knowledge and skills with their teammates. Such a peer interaction structure can be described by an asymmetric public goods game as students' knowledge and abilities differ according to their backgrounds and unobserved characteristics, and knowledge sharing is a typical example of a social dilemma. A rich laboratory experiment literature suggests that collaboration would be less successful in a heterogeneous rather than a homogeneous setup, because the tension between highly and less endowed members is usually intense. For example, in a team where endowments are unequally distributed, members' endowment sizes are known to be negatively correlated with their levels of cooperativeness in the voluntary provision of a public good (e.g., Chan *et al.*, 1996; Kamei, 2018; Maurice *et al.*, 2013). For example, in Kamei (2018), while the average contribution of the highly endowed was less than 10% of their endowment, that of the least endowed was more than 50% of the endowment on average.

Further, a negative effect of productivity heterogeneity in teams among team members was also reported. For example, Fischbacher *et al.* (2014) experimentally showed that heterogeneity in returns, i.e., marginal per capita return (MPCR), from contributing to a public good undermines cooperation, perhaps driven by members' pessimistic beliefs about others' contribution behaviors.[2]

In sum, this strand of the literature suggests higher academic performances through more successful collaboration in homogeneous rather than heterogeneous teams. Having said that, the previous experiments listed above were conducted under *anonymous* conditions in a laboratory (where subjects' identities, such as faces and names, were not revealed to each other) and also subjects' individual contribution decisions were not verifiable since the experiments were designed based on public goods games with group sizes of at least three. Hence, the earlier findings may not apply to the setup of the present study since students' interactions within pairs in the peer review assessment activities are made with full transparency here. Literature in (b) in fact suggests the positive impact of observability – see Section 2.2. Most of the empirical research or randomized field experiments in literature (b) and (c) used non-anonymous setups, finding the superiority of team heterogeneity – see Sections 2.2 and 2.3.

2.2. Peer Pressure and Productivity

There is a substantial literature, both theoretically and empirically/experimentally, for the role of peer pressure on influencing behaviors. Much theoretical research suggests that having detailed information about members' behaviors per se, such as through peer review assessment

[2] The positive impact of homogeneity is not limited to the distribution of resources or productivity. Prior experimental research on sorting in public goods games found a higher level of cooperation when like-minded individuals (in terms of cooperative dispositions) are grouped together rather than otherwise, although whether cooperation norms prevail in a group depends on the group's cooperativeness – for example, see, Gunnthorsdottir *et al.* (2007) and Gächter and Thöni (2005). In Page *et al.* (2005), even the average contribution of groups where less cooperative subjects were grouped together were not that low under sorting.

activities in the present study, may trigger positive effects on work performance. For example, working in teams could trigger social image concerns among members, thereby encouraging hard work to be recognized by others (e.g., Bénabou and Tirole, 2006 and 2011). Because high observability makes it possible to compare self with others, teamwork could also trigger social effects, such as guilt, shame and pride, among members in teams (e.g., Bowles and Gintis, 2015), hence inducing them to study harder to achieve better academic grades.

Laboratory experiments support the idea that high visibility encourages socially desirable behaviors under certain conditions: e.g., voluntary contributions to a public good (e.g., Samek and Sheremeta, 2014), direct punishment of norm violators (e.g., Kamei and Putterman, 2015), third party enforcement of social norms (e.g., Kamei, 2018), and charitable-giving (e.g., Ariely *et al.*, 2009; Soetevent, 2005). For example, in a real-effort experiment where no material incentives were associated with the amount of effort, Ariely *et al.* (2009) demonstrated that worker subjects exert greater endeavors for charity when they have to tell others about their own donation amounts than when their identities and acts remain anonymous. In the context of this study, students can realize their partners' achievement levels in the peer review assessment activities, which would give the less able student in a pair an incentive to work hard *in* (and also perhaps *after*) the peer review activities so that (s)he can avoid incurring disutility due to such information effects from her/his weaker performance being seen by her/his paired mate. This kind of behavioral effect would be larger, the larger ability difference a pair has. Hence, it can be predicted that the learning effects of peer review activities would be on average larger in pairs with heterogeneous than with homogeneous abilities.

The information effect in pairs is not limited to the social effects. For example, information about peers' greater endeavors and/or performance may change the reference points of the less able students (e.g., Abeler *et al.*, 2011). For example, Shang and Croson (2009) found that people donate larger amounts when they are informed of others' active charitable-giving behaviors, even if own donation amounts are kept private (also see Croson and Shang [2008]). This line of the literature again suggests that students' learning outcomes in the present paper would on average be higher in pairs with a greater spread in abilities and skills, since the less able students can become aware of their academic positions through the peer review assessment activities, thereby updating their expected study behaviors. This prediction may be reinforced by the fact that workers are on average known to have overconfident and biased beliefs about own ability (e.g., Langer, 1975; Svenson, 1981; Larkin *et al.*, 2012).

During the last two decades, economists have devoted considerable effort into identifying peer pressure and interactions in realistic setups using randomized field experiments. Prior research can be broken into either (i) peer effects with (possible) social interactions – simply "peer effects," hereafter (e.g., Katz *et al.*, 2001; Sacerdote, 2001; Carrell *et al.*, 2009; De Grip and Sauermann, 2012)[3] or (ii) peer effects without direct interactions – "pure peer effects," hereafter (e.g., Falk and Ichino, 2006; Guryan *et al.*, 2009; Brune *et al.*, 2022).

The research area of (i), the closest to the present experiment, suggests positive peer effects. For example, based on random assignment of university students to dorms and roommates, Sacerdote (2001) found that assigned peers have a strong impact on own academic achievement measured by grade point average – see also Carrell *et al.* (2009) who showed similar academic peer effects for random assignment of students to large peer groups called squadrons. In the context of residential neighborhoods, Katz *et al.* (2001) likewise found positive peer effects, based on a research design with random assignment of housing vouchers to poor families. In the context of the workplace, De Grip and Sauermann (2012) studied peer effects among call agents (who work individually) in call centers. They found that work-related training not only improves the worker productivity, but it also leads to an increase in the productivity of coworkers that did not participate in the training program. These positive peer effects can be thought of as having two components: (a) the mere effects from high visibility and the presence of peers, and (b) local social interaction effects.

While these studies successfully provide insights into the role of peers, suggesting that peer effects lead to similar behavioral outcomes among peer mates, the recent literature further advances the mechanisms behind peer effects by exploring how it is affected by team heterogeneity. Its main finding is on the superiority of heterogeneous teams in terms of abilities, and peer effects differ largely by the ability and achievement level. The research discusses that high-ability (-achieving) individuals gain more than low-ability (-achieving) ones in a heterogeneous team (e.g., Lyle, 2009; Duflo *et al.*, 2011; Carrell *et al.*, 2013; Feld and Zölitz, 2017; Booij *et al.*, 2017). This is because the former tend to benefit more from like-minded high types in social interactions within a heterogeneous team, as they *selectively* form sub-teams with like-minded high types, while low-ability (-achieving) individuals are hurt in peer interactions. Such sorting is not possible in homogeneous teams. The proportion of females in a peer group is also known to enhance positive peer effects (e.g., Black *et al.*, 2013; Lavy and Schlosser, 2011; Lu and Anderson, 2015).

Albeit quite convincing, one issue for some randomized field experiments with a large scale, such as Sacerdote (2001), is its internal validity of the research in that there are no controls

[3] Roughly speaking, this can also be called social effects in the term used by Charles Manski (e.g., Manski, 1993).

for the ways in which individuals interact with each other locally. This means that one is unable to underpin what kinds of social interactions exactly triggered the positive peer effects in these studies. The present paper uses a microenvironment that clearly specifies who interacts with whom, and in what way. As discussed in Section 3, each student, divided into either treatment or control groups, has the same learning activities with their assigned partner using a pre-determined pair activity. The intervention may create positive peer interactions locally to achieve their individual goals.

Another common feature of the prior research is that peer groups are large in most papers: for example, the peer group size is a squadron consisting of 30 students in Carrell *et al.* (2009), 35 cadets per company in Lyle (2007, 2009), and 10-15 students per classroom section in Feld and Zölitz (2017). While a large peer group size is ubiquitous in our real lives, a smaller peer group is also equally common (e.g., pair work in an academic environment such as a classroom, police officers patrolling in pairs). The present paper uses the minimum peer group size – a two-person pair. The use of the smallest size has a methodological advantage as a better control: its setup makes it possible to specify who interacts with whom, while classifying a better or worse performer in each pair, and excluding possible formation of sub-teams. This setup may lead to a result different from the earlier established finding on the heterogeneous treatment effects. For example, worse performers may benefit more through peer learning since their paired better performers have no choice but to interact with them in the activity. This paper supplements a large body of the prior research with randomized field experiments by providing clean evidence on the role of team heterogeneity in peer interactions when the peer group size is sufficiently small.

It is not possible to identify how large the pure peer effects would be according to literature (i). This question was investigated by using clever setups with high internal validity by various sets of authors, for example, in the context of part-time jobs by Falk and Ichino (2006), pluckers working in an agricultural firm by Brune *et al.* (2022), and professional sports tournaments by Guryan *et al.* (2009). Most studies, such as Falk and Ichino (2006) and Brune *et al.* (2022), found positive pure peer effects, although some studies (e.g., Guryan *et al.*, 2009) did not find such effects. While the sizes of pure peer effects vary largely across the labor markets and different contexts, a meta-analysis in fact showed that pure peer effects would be on average positive (Herbst and Mas, 2015).

2.3. Mutual Learning Theory

A rich body of the empirical literature in labor and personnel economics discussed that social interactions (e.g., communication) among peers and training help improve individual productivity. For example, Ichniowski *et al.* (1997) documented that innovative human resource management practices used in steel finishing lines improved productivity. The practices include enhanced communication practices among workers and skills training, combined with many other aspects such as high involvement in teams and employment security. Using data from a garment plant, Hamilton *et al.* (2003) found that, while given a choice workers sorted into teamwork, rather than individual work, teams with a greater spread in abilities were more productive under *team*-based remuneration. They discussed that this phenomenon can be explained by an intra-team bargaining model (i.e., high-ability workers impose strong norms) and the mutual learning theory (i.e., high-ability workers teach less-ability ones).

While the prior research was successful in showing the importance of incentives, peer learning and team heterogeneity, it is not possible to measure the effects of peer learning in isolation, since the practices contain at least several dimensions at the same time. It is also not clear how more able workers teach less able workers if each worker is compensated based only on their *individual* performance.

The impact of productivity spillovers was also empirically identified in specific sectors, suggesting that it may be positive. For example, Arcidiacono *et al.* (2017) showed that productivity spillovers among professional players play an important role in the team outcomes in the National Basketball Association. Mas and Moretti (2009), using high-frequency scanner data, showed that introducing a high-skilled cashier to a shift would improve other cashiers' productivity in supermarket chain stores. See also Azoulay *et al.* (2010) for research productivity spillovers among academics and Jackson and Bruegmann (2009) for the case of teaching effectiveness in elementary schools. Nevertheless, it is unclear exactly what kinds of social interactions or learning (if any) triggered positive effects on those involved in the prior studies.

3. Background, Experimental Design and Procedure

The Introduction to Economics module (ECON1101) is a core compulsory module that all the first-year undergraduate students in finance and accounting (a total of 250 to 350 students dependent on the year) must take at Durham University. A "module" is a term used in the United Kingdom to refer to a course. Teaching in a module is organized and implemented by a teaching team. As the very first economics module, students learn the basic principles of economics, and the module serves as a foundation for upper-year core modules in micro- and macroeconomics. Even though it is the first introductory course, because Durham University is highly ranked in the United Kingdom with high quality entrants, students learn some technical aspects, such as mathematical calculations for Cournot competition, the Solow growth model and the IS-LM model. ECON1101 consists of ten weeks to study microeconomics (term 1) and nine weeks to study macroeconomics (term 2) – see Figure 1. The students' final assessment is evaluated solely based on one written examination (summative assessment, hereafter) which takes place at the end of the academic year (at the end of May). The maximum (minimum) mark given is 100 (0). Each student will be given an academic grade based on their *own* mark. The grade is: first class (≥ 70), second class (below 70 but ≥ 50), third class (below 50 but ≥ 40), or fail (below 40). Both the raw mark and grade will be written in the student's official transcript.

The summative assessment consists of three parts: Parts A, B, and C. Part A consists of two short-answer questions, each of which accounts for 10% of the assessment mark. Part B (C) consists of two questions from microeconomics (macroeconomics), and each student must select one of the two questions. Parts B and C each account for 40% of the assessment mark. Most questions are essay-type (the summative assessment can be found in Supplementary materials Section A.7). The examination is held online and students need to complete the problem set in a 48 hours window when the problem set is distributed.[4] There is a rigorous word limit: the maximum word count is 3,750 words (markers will stop reading once the maximum word count is reached).[5] Students are instructed not to copy and paste from textbooks or lecture notes (copies and pastes are not given marks). A plagiarism check is also performed for each script by the undergraduate office and also by the Turnitin software. Kamei was the module leader for ECON1101 for the 2019/20 academic year and Ashworth was the department head when the randomized field experiment was planned before the academic year started (he was the department head from 2016 to 2019). The experiment was designed and implemented using the students of this module for the 2019/20 academic year.

Students have four key learning activities. The first one is weekly two-hour lectures. Kamei delivers lectures in term 2, while another faculty member does so in term 1.[6] The lectures are held in a large lecture hall, and all students take the same sessions. The lectures are designed to introduce the key economic concepts and methods, and to present the technical analysis in action. They are always accompanied by presentation slides (and sometimes also mathematical

[4] The summative assessment is released on May 25, 2020 at 9 am, with the deadline being May 27 at 9 am.
[5] Marking is operated through a rigorous double-marking procedure. The university appoints first markers and second markers in this module. When each first marker finishes marking their assigned set of scripts, second markers independently determine marks on randomly selected scripts (see the University's Learning and Teaching handbook).
[6] Lecturing of macroeconomics is the only teaching duty of Kamei. Kamei is responsible for the management of the module (e.g., coordinating with the other lecturer in term 1, monitoring the teaching work of seminar tutors during terms 1 and 2). The allocation of teaching and the make-up of teaching teams and duties within the teams are determined by the department with the members of staff informed of the team and responsibilities for the model prior to the start of the 2019/20 academic year.

handouts) whose electronic files are distributed to every student through a Blackboard (DUO) prior to the lectures. The lecture time is not designed as interactive (rather one-way delivering of key concepts), although students have some opportunities to raise issues and confirm their understanding of the analysis. Other than lectures in terms 1 and 2, there are two additional lectures (one for microeconomics, and the other for macroeconomics) in term 3, i.e., revision periods, as reviews before the summative assessment.

Second, students have one-hour mandatory seminars in every other week (a total of four seminars for microeconomics in term 1 and another four for macroeconomics in term 2). The students in accounting and finance are allocated to one of the 16 seminar groups by the undergraduate office.[7] Each seminar group has around 15 to 20 students. There are three tutors in the module. One tutor is responsible for seven seminar groups in term 1, while another tutor is responsible for the other nine groups in term 1.[8] The third tutor is responsible for all 16 seminar groups and uses the same instruction across the 16 groups in term 2. This would minimize the possible effects of common shocks (e.g., Lyle, 2007). Students' learning could, nevertheless, be affected by their assigned seminar group since they have social interactions there. Hence, seminar group clustering is included for all data analyses such as regression analyses in Section 5.

A problem set is distributed to students one week prior to a given seminar session, and students are expected to attempt those questions before the class. Seminars are designed to be interactive. While a seminar tutor explains the answer, students are also invited to discuss their answers in their seminar group. This means that the unit of independent observation is seminars. Students' attempts before the seminar are not checked (nor do these activities contribute to students' final marks). However, attendance at seminars is mandatory and registers are taken in all sessions as an important academic commitment.[9]

Third, students have one formative assessment – simply "formative" hereafter – in each term (two pieces in total). Students must answer a problem set and submit their answers officially to the university. The term 1 formative asks questions on the producer theory, while the term 2 assessment asks those on the short-run macroeconomics – see the problem set in Supplementary materials Section A.3 and A.5. The seminar tutors mark the scripts online, and

[7] The undergraduate office (using a University algorithm) is fully responsible for the allocation. Anyone in the teaching team, including the module leader (Kamei), is not at all involved in the allocation process.
[8] As students' performances might be affected by the difference in the seminar tutor in term 1, term 1 tutor assignment is controlled by having a dummy variable when estimating treatment effects in data analysis (Section 5).
[9] Students were also informed: "Failure to attend without a prior arrangement will be noted and any student who misses a seminar without having made a prior arrangement should attend their tutor's next consultation hour. Persistent absences will result in our instigating formal monitoring processes."

provide individual feedback to each student. While the marks are not be counted towards their final marks, they are recorded in the students' information sheet in the university. The formative aims to help students understand the material and its applications in a structured way, as well as help them prepare for the summative assessment. An intervention was made in term 2 utilizing the students' performance in the term 1 formative (further details below).

The above three learning activities are identical to all students, but the fourth activity is a peer review assessment (PRA), for which a randomized control trial is implemented. This activity starts earlier than the formative assessment in each term. In the PRA activity, students are first distributed a problem set whose format is the same as the formative (e.g., on October 28, 2019 for term 1), attempt the problems independently, and then submit their scripts officially to the university (e.g., the submission deadline is November 8, 2019 for term 1). The term 1 PRA asks questions on the consumer theory, while the term 2 assessment asks those on long-run macroeconomics. Notice that the topic of the PRA is different from that of the formative in each term. The problem set can be found in Supplementary materials Section A.2 and A.4. Once the submission deadline passes, students are informed of their pair partner (e.g., on November 11, 2019 for term 1). The seminar tutors collect students' scripts of the respective seminar groups from the undergraduate office and give students their partners' scripts during the following seminars. Each pair works together to discuss the problem set and their scripts. The procedure uses a proforma prepared by the authors – see Supplementary materials Section A.6 for the proforma in term 2 as an example. Specifically, each student critically assesses their partner's script by completing Part A of the proforma for each question, has a meeting in their pair, gives their partner the proforma so that the partner can write afterwards what they learned from the activity, and also jointly decide on an agreed mark for the script. Students must submit the proforma officially to the undergraduate office. The students go through the whole process *without* seeing answer sheets of the PRA problem set: a solution to the problem set is distributed to students in each term *after* the deadline of proforma submission passes. Each pair is encouraged to study and find answers by themselves if both the students in the pair did not solve the problem set. The timeline of the assessment, along with other module activities, can be found in Figure 1 (also in Supplementary materials Section A.1).

In term 1, in the PRA activities, all students are randomly broken into pairs in their respective seminar groups. When the number of students in a given seminar is odd, there is one team consisting of three students. In term 2, by contrast, seminar groups are randomly assigned either the random matching condition ("treatment condition") or the sorting condition ("control condition") so that the number of seminar groups in each condition is 8 out of 16. On the one hand, students in a group with the treatment condition are randomly broken into pairs as in term 1. The pairing is completely random, implemented through computer random number generation.[10] On the other hand, students in the control condition are sorted in descending order according to their term 1 formative assessment marks, and pairs (teams) are formed so that their marks are adjacent to each other.[11] Any student is *not* aware of this paring process.

In order to study how the PRA activities affect their focus on preparing for the summative assessment, one question comes from the consumer theory (long-run macroeconomics) and the other comes from the producer theory (short-run macroeconomics) in Part B (Part C) in the summative assessment. In other words, the topics of the four questions appearing in Parts B and C are covered by the two formatives and two PRAs in the module. The students were not given any information in advance regarding which topics would be tested in the summative assessment.

To maximize the external and internal validity of the project, it is essential for students to engage in the learning activities without knowing the presence of on-going experiments or the matching differences by seminar group. The institutional review board (IRB) at Durham University, however, asked the authors to seek consent from the students and explain a possible research activity. As a compromise, the research team simply includes a generic consent statement in the proforma of the term 1 peer review assessment without writing any substance of the research as follows:

> Consent:
> Your assessment marks may be used for the purpose of further research and to enhance the learning experience for the programme. I consent this possibility.
> Your Signature: ____

The performance of only those who gave us consent are used for the study (this procedure has been approved by the IRB).[12] Hence, students in the module are not aware of any experimental aspects. Students are simply informed of the learning objective of the PRA activities using the materials in Supplementary materials Section A.1.

To further enhance the internal validity of the experiment, all members of the module teaching team perform lecturing, tutoring and consultation following the module outline and the

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[10] There is an exception in which the same four pairs as in term 1 were formed by chance and hence the pairing was further randomly changed to ensure that all students had different partners for terms 1 and 2.

[11] The same eight pairs as in term 1 was formed by sorting. Their pairing was adjusted by the authors, swapping the partners among similar interim marks so that all students had different partners.

[12] Another condition in obtaining the IRB approval is for us not to make any student's proforma publicly available.

requirement set by Kamei, without being informed of the on-going experiment. Moreover, all administrative staff members in the undergraduate office are likewise uninformed of the presence of the experiment. Note that Kamei does not serve as a tutor of any student in the module. Seminar tutors deal with all aspects of the PRA activities as well as direct interactions with students in seminars. Kamei's minimum interactions with the students help minimize a possible unconscious bias that might have occurred had he tutored any of the students.

4. Hypothesis

Either the presence of social effects through social comparison, such as shame and pride, or the mutual learning proposition and interdependent motives, predicts that (i) students perform better on the summative assessment in pairs with a greater spread in interim performances, and (ii) the worse performers in the treatment condition improve performance through working with their matched better performers. The present experiment does not aim to distinguish between these two plausible behavioral motives, but it rather examines an empirical question on the effects of pair heterogeneity on performance. As will be explained in Section 5, the experiment results do support both of hypotheses (i) and (ii) above. Sorting out the main motive behind these affirmative results would be an exciting direction for future research.

This section briefly and intuitively illustrates the mechanisms regarding what hypotheses are derived by these motives. Appendix C provides a mathematical analysis that examines the mechanism of each motive in isolation. While the analysis below discusses three variables (students' effort, academic performance and utility) for a discussion purpose, the focus in the field experiment is the effects of peer learning on academic performance.

4.1. Performance Prior to the PRA Activities

Without the PRA activities, each student's performance is solely determined by their own effort exerted in the module since students have neither a social comparison process nor a mutual learning possibility. Assume the following payoff functional form to describe the situation prior to engaging in the PRA activities for $i = h$ (high type) and l (low type):

$$G_i(y_i) = g(y_i) - \gamma_i {y_i}^2. \tag{1}$$

$$g(y_i) = \alpha_i + \beta_i y_i. \tag{2}$$

Here, $g(y_i)$ is the i's interim performance gauged by the formative in the module, y_i is the effort put so far by type $i \in \{h, l\}$ to learn class materials, and $\gamma_i {y_i}^2$ is the cost associated with the effort provision. The parameter values are set such that $\alpha_h > \alpha_l > 0$, $\beta_h > \beta_l > 0$, and $0 < \gamma_h < \gamma_l$ (i.e., the high type has a higher return from effort and a lower unit effort cost than the low type).

Each type's optimal interim effort provision can then be derived by using the first-order conditions for (1) and (2):

$$y_i{}^* = \frac{\beta_i}{2\gamma_i}. \tag{3}$$

Note that $y_h{}^* = \frac{\beta_h}{2\gamma_h} > y_l{}^* = \frac{\beta_l}{2\gamma_l}$, which means that both the academic achievement *g* and the utility *G* of the high type are better than those of the low type from Equations (1) and (2).

4.2. Behavioral Effects through the PRA Activities

As the PRA activities can improve each other's performance through mutual learning, the payoff functions after the activities can be re-written as below:

$$\pi_h(y_h, e_h|e_l) = G_h(y_h) + a_l e_l - c_h e_h{}^2 = g(y_h) + a_l e_l - \gamma_h y_h{}^2 - c_h e_h{}^2. \tag{4}$$

$$\pi_l(y_l, e_l|e_h) = G_l(y_l) + a_h e_h - c_l e_l{}^2 = g(y_l) + a_h e_h - \gamma_l y_l{}^2 - c_l e_l{}^2. \tag{5}$$

In these equations, e_i is the effort level provided by $i \in \{h, l\}$ to teach their partner through critical assessment of the partner's script and discussions. For simplicity, consider a case where the effort provision by *i* does not benefit *i* personally. The cost function is assumed to be quadratic, i.e., $c_i e_i{}^2$, such that $c_l > c_h$ (the unit effort cost in the PRA activities is higher for the low than for the high type). $a_l e_l$ ($a_h e_h$) is the benefit that the high (low) type receives from their matched low (high) type in the pair, and $a_h > a_l$. The second equalities of (4) and (5) are obtained by substituting $G_i(y_i)$ with Equation (1).

Clearly from Equations (4) and (5), if both types are purely selfish, $e_i = 0$ for all $i \in \{h, l\}$ as the PRA activities are just costly. This means that y_i is characterized the same as Equation (3), and therefore their academic achievements are not affected by the PRA activities. However, the academic performance would change if it is additionally assumed that (a) social effects, such as shame and pride, or (b) interdependent preferences, are present. While each behavioral motive leads to different behavioral changes as described from now on, they both improve academic performance of the low-type student.

A student's feelings of shame or pride through social comparison can be modeled by assuming that a student receives a positive (negative) utility when their own class performance is better (worse) than their pair partner's. On the other hand, their interdependent preferences can be modeled by assuming that each type incurs a utility loss if their utility from effort provision is not the same as their pair partner's. For an illustrative purpose, consider the following utility function θ_i:

$$\theta_h(y_h, e_h|e_l) = \pi_h(y_h, e_h|e_l)$$

$$+\mu_h[\{g(y_h)+a_l e_l\}-\{g(y_l)+a_h e_h\}]^2 - x_h\cdot(\pi_h-\pi_l)^2. \quad (6)$$

$$\theta_l(y_l,e_l|e_h)=\pi_l(y_l,e_l|e_h)$$

$$-\mu_l[\{g(y_h)+a_l e_l\}-\{g(y_l)+a_h e_h\}]^2 - x_l\cdot(\pi_h-\pi_l)^2. \quad (7)$$

The differences between Equations (4) and (5) and Equations (6) and (7) are the presence of the second and third terms in the latter. First, the second term describes social effects. The equation in the squared brackets (i.e., $\{g(y_h)+a_l e_l\}-\{g(y_l)+a_h e_h\}$) is the intra-pair difference in the achievement level after the PRA activities. The assumption here is that the high (low) type has feelings of pride (shame), which leads to a positive (negative) utility. μ indicates each type's utility weight on the social effects, such that $0<\mu_h<\mu_l$. This condition means that the impact of shame is stronger than that of pride. Second, the third term, $x_i\cdot(\pi_h-\pi_l)^2$, indicates each type's interdependent preference with x_i (where $x_i>0$) being i's utility weight on the interdependent preference. The assumption for the interdependent preference is that a student prefers to have *similar* payoffs between pair mates.

The presence of the social effects ($\mu>0$) per se does not encourage peer learning, as the high type prefers to have a large performance difference to enjoy the feelings of pride. However, the social effects can have students update the levels of their study effort y in the PRA activities, as the low type can reduce the utility loss due to feelings of shame by increasing y_l, and the high type can increase the utility gain from feelings of pride also by increasing y_h. Such updating is larger, the larger the intra-pair performance difference is. As detailed in Appendix C.1, the low type makes a stronger academic improvement than the high type if the effect of shame is sufficiently larger than that of pride. It should be noted here that feelings of pride and shame encourage the students to work beyond $y_i{}^*$ (Equation (3)), i.e., the efficient levels in terms of their effort costs. This means that having a social comparison process in the PRA activities may not enhance their utilities.

On the other hand, the presence of interdependent preferences (i.e., $x_i>0$) can predict a pattern of the mutual learning hypothesis, as illustrated in Appendix C.2. As there is a difference in the utility level between the high and low types in a pair at the interim stage, the high type is motivated to teach their matched low type by putting effort e to reduce the utility loss from inequality provided that their utility weight on inequality is sufficiently large, thereby improving the performances of the low-type student. This mechanism works best when the intra-pair ability difference is large, because then the utility loss is large without such teaching.

In sum, the mechanism is different depending on which motive is considered: while social effects encourage low types to increase their self-study efforts y_l in the PRA activities to show their pair partners that they are good, interdependent preferences encourage high types to teach their matched low types by putting best effort e_h. However, whichever motive is assumed, both the motives predict that the low types improve their academic performance more than their matched high types, and the impact is larger, the larger interim performance difference a pair has.

Hypothesis: *(a) The larger interim performance difference a pair has, the greater academic improvement the pair achieves through the PRA activities. (b) The strong academic achievement is driven by an improvement in the low type's performance.*

5. Results

284 students enrolled in the module at the beginning of the academic year. Almost all the students remained in the module when final module registrations emerged after the student review period.[13] The total number of students was 279 at the beginning of term 2. 92.8% of them gave consent for their data to be used for possible research. As a result, the subject pool includes 129 and 130 students in the treatment and control conditions, respectively. Table 1 summarizes students' performance in term 1 formative assessments. It indicates that almost all the students submitted the formative assessments. This is not a surprise since the submission of the formative assessment was compulsory. The average mark of the formative assessment was 70.38 in the treatment condition, somewhat lower than that in the control condition (72.05). However, the difference is not statistically significant according to a Somers' D test with seminar group clustering (two-sided $p = 0.721$).[14] This means that the random allocation of matching conditions was successful. In the subject pool, 123 and 127 students in the treatment and control conditions, respectively, completed summative assessments by the deadline.

Table 1 also includes information on the proportions of female students and those of British students. First, the proportion of female students is somewhat smaller in the treatment than in the control condition. Prior research suggests that having a higher proportion of female peers helps improves performance (e.g., Black *et al.*, 2013; Lavy and Schlosser, 2011; Lu and Anderson, 2015). If this is applicable for the student pool of this study, students may tend to achieve better academic performance in the control than in the treatment condition at the final assessment.[15] Second, the proportion of British students is somewhat larger in the former than in the latter. "Home" or British students have broadly similar academic backgrounds and

[13] This is as expected since ECON1101 is a compulsory module.
[14] Testing based on Somers' D is identical to the Mann-Whitney test if clustering is not included.
[15] As will be explained in this section, students performed significantly better in the treatment than in the control condition despite the somewhat lower percentage of female students in the former.

understanding of institutional norms and so have a potential in-built advantage in the first year. However, in any case, the differences in these two proportion measures are not significantly different between the treatment and control conditions. Thus, it can be concluded that these demographics are sufficiently balanced between the two conditions.

As explained in Section 3, students' attendance in bi-weekly seminar activities were set mandatory in the module. Some students missed the seminars, nevertheless (Figure 2). The average attendance rates show similar trends for the treatment and control conditions. The rates were high at the beginning of each term, and then gradually declined from seminar to seminar. The attendance rates were around 70% (somewhat over 60%) in the fourth seminar in term 1 (term 2). A Somers' D test with seminar group clustering found that the difference in the average seminar attendance rate was not significant between the treatment and control conditions at two-sided $p = 0.470$. This means that students' exposure to the seminar activities were also balanced.

The learning outcome in this module can be measured based on students' performances in the summative assessment at the end of the academic year. The data show that despite the slightly weaker interim (term 1 formative) performance in the treatment than in the control condition (Table 1), students in the treatment condition achieved better marks in the summative assessment. As shown in panel A of Figure 3, the difference in the average mark between the two matching conditions was around three points and is significant at two-sided $p = 0.031$ according to a Somers' D test with seminar group clustering. In particular, while students in the bottom 10% showed similar achievements in the two conditions, the rest (90% of students) showed higher achievements in the treatment than in the control condition.

In term 2, a small fraction of students did not submit peer review assessments.[16] Even if students did not submit the PRAs, they were still encouraged to meet with their partners and discuss the problem set within the pairs as an academic commitment, meaning that there might have still been some effect. However, having an effective discussion could be difficult without having their partners' scripts. Hence, it would be useful to study a possible treatment effect while limiting data to pairs in which both pair mates submitted the PRAs. Panel B of Figure 3 reports the cumulative distributions for the restricted dataset. It shows an almost similar pattern to panel A and the performance difference is significant at two-sided $p = 0.034$ according to a Somers' D test with seminar group clustering. This suggests that the size of the treatment effect was not affected by the omission of those who were not able to complete the PRA activities.

[16] 11 students (4.23% of the students in the subject pool) did not submit the assessments in term 2.

Care needs to be exercised when formally studying the treatment effect of intervention, especially because not all students completed the summative assessments (i.e., submitted by the deadline). The data indicate that among the 259 students who gave consent, nine students (3.47% of the subject pool) did not complete the assessment. No submission for "good cause" is treated as different from zero marks in the exam with the university.[17] As their marks were unobserved, a Heckman two-stage selection model was used to control for a possible impact of the selection bias although the effect of selection bias seems to be very small. Considering that students' effort levels put into the module may explain their decisions to complete the exam, their attendance rates in seminar activities and submission records of formative assessments are included as independent variables in the first-stage selection equation.[18] As shown in Table 2, the model was estimated when using all data (columns I.i and I.ii) or using students who submitted the term 2 PRAs (columns II.i and II.ii). The t2 (term 2) random matching dummy is included in all the specifications to estimate the effect of treatment intervention.

The estimation first reveals that, as expected, students' effort exerted in the module are good predictors for their completion of the summative assessment: the number of formative assessments not submitted has a significantly negative coefficient in the first-stage selection equation. In addition, as shown in columns I.i and I.ii, the seminar attendance rate variable has a significantly positive coefficient when all eligible subjects are considered.

Second, and most important, regardless of whether the students' term 1 formative marks are controlled for, the t2 random matching dummy consistently has a significantly positive coefficient in the second stage regression. This suggests that working in pairs with different abilities leads to a higher performance than pairing students whose achievement levels were similar to each other, in support of the view from the peer-effect hypothesis and the mutual learning theory.[19]

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[17] For example, if a student had a valid reason, such as illness, for not attending, there would be a blank in their transcript; they can take a resit exam as their first attempt. The authors do not have accessible data regarding reasons for not attending the exam or resit marks.

[18] A given student's seminar attendance rate was calculated based on the eight seminar activities in the module. It should be acknowledged that in one seminar group, the seminar tutor failed to take attendance in the eighth seminar; thus, the attendance rates of students in that group were calculated based on the records in the other seven seminars. Results reported in this paper do not change qualitatively even if students' attendance rates are calculated based on the seven seminar activities for all seminar groups.

[19] The gender composition in pairs may affect the size of peer effects (e.g., Black *et al.*, 2013; Lavy and Schlosser, 2011; Lu and Anderson, 2015). However, in principle, individual characteristics do not need to be controlled in this study since matching conditions were randomly assigned to groups and the proportion of female students was not significantly different between the treatment and control conditions (Table 1). Nevertheless, an additional regression was conducted as a robustness check while controlling for available demographic variables (own gender, pair

Result 1: *Consistent with Hypothesis a, students in pairs with a great spread in interim achievement levels performed better on the summative assessment compared with those in pairs whose interim performances were similar to each other.*

What drove the positive impact of the PRA activities in term 2? The only difference between the two conditions is the use of random matching or sorting in the pairing process. Students in the control (sorting) condition were divided into pairs so that their term 1 formative assessment marks were similar to each other. By contrast, pairing was randomly formed for students in the treatment (random matching) condition. With this difference in the matching protocol, the average intra-pair absolute difference in the formative mark was more than four times in the treatment than in the control condition: it was 25.16 (5.81) marks with clustered standard errors of 3.28 (1.07) marks in the former (latter). Panel A of Supplementary materials Figure B.2 reports the histogram of absolute individual performance differences by the matching condition. It clearly indicates that the differences spread widely to the right in the treatment condition, while they are concentrated around 0 in the control condition. Hence, these patterns confirm that, as intended, pairs in the treatment condition had a greater variation in interim achievement levels between pair mates, compared with those in the control treatment.

In order to study how the treatment effect differs by the intra-pair relative term 1 performance standing in the treatment condition, the data in the treatment condition was split into two sets: the "better performers" and the "worse performers." The better (worse) performer is defined as a student whose term 1 formative mark is better (worse) than that of their matched partner in a term 2 pair.[20] The average term 1 formative marks of the better and worse performers were 80.35 and 57.81, respectively, in the treatment condition (the average mark in the control condition was in the middle between the two, and it was 72.05 as already discussed in Table 1) – see also panel B of Supplementary materials Figure B.2. Intriguingly, the performance data in the summative assessment by the relative standing reveal that the better and worse performers had similar achievements in the end, scoring 71.31 and 71.94 points, respectively, each of which was better than the average summative performance under sorting (Table 1).[21] This seems to suggest that working in a team with a greater spread in abilities strongly supports the learning of the worse performer.

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partner's gender, and the interaction between the two gender variables, students' nationality). The estimation found qualitatively similar results, i.e., positive effects of having a greater spread in abilities in a pair – see Supplementary materials Table B.1 for the detail.

[20] There was no student whose term 1 formative mark was exactly the same as their partner's.

[21] The absolute sizes of marks are not perfectly comparable between the formative and summative assessments because the former has only one problem set while the latter has multiple problem sets.

A regression was performed by including two indicator variables – the better performer and the worse performer dummies – as independent variables, to formally study the role of relative performance standing in the treatment condition. Having the two dummies make it possible to identify how the aggregate positive effect of term 2 random matching (Result 1) differs by student's interim achievement standing. The reference group is the students in the control condition.

Table 3 reports the estimation results. The regression only uses the data from pairs in which both the pair mates submitted term 1 formative assessments, since otherwise it is not possible to judge which student was the better or worse performer in the interim stage. A Heckman selection model was again used in the analysis in order to deal with unobserved summative marks of some students. As shown in columns I.i and II.i, when only the two performance dummies are used as independent variables in the second stage equation, the dummies obtain weakly significantly or significantly positive coefficients. This implies that not only the worse but also the better students might have similarly benefited from the PRA activities in the treatment condition. However, this interpretation is misleading. As shown in columns I.ii and II.ii, once students' term 1 formative assessment marks are controlled for, only the worse performer dummy obtains a significantly positive coefficient at the 5% level or better. It follows that the results from columns I.i and II.i are subject to a selection bias: the better (worse) performers in the treatment condition had better (poorer) skills than the average student in the control condition. In other words, the significant coefficients for the better performer dummy in columns I.i and II.i are driven by the differences in the term 1 formative marks between them and the students in the control, and the worse performers in pairs are the ones that mainly benefited from the PRA activities in the treatment condition.[22]

It should be worth noting that the coefficient estimates for the better performer dummy are not negative, but close to zero, in columns I.ii and II.ii. This means that the better performers were not hurt by being matched with the worse performers.

While the analysis just discussed was performed by splitting students in the treatment condition into better and worse performers based on their intra-pair performance differences, it is also meaningful to study the effects of learning from an absolute perspective, i.e., by classifying whether a student's interim performance gauged by term 1 formative was above the median mark in the module or not (the "above-median" performer or "below-median" performer,

[22] With the same reason as written in footnote 19, an additional regression was conducted while controlling for demographic information as a robustness check, finding almost the same as in Table 3 (see Supplementary materials Table B.2).

hereafter).[23] This alternative approach makes it possible to examine how different pairings in the term 2 PRA activities affected the performance of the "above-median" and "below-median" performers in the summative assessment. Appendix Table B.4 reports regression results when using dummy variables that indicate different pairings as independent variables, instead of the better and worse performer dummies, in the same specifications of Table 3. The results show similar patterns to those of Table 3: (a) the "above-median" performers at the interim stage were not hurt by being matched with a "below-median" performer in the PRA activities, while (b) the "below-median" performers benefited significantly by being matched with an "above-median" performer.

Result 2: *Consistent with Hypothesis b, the worse performers in the treatment condition improved performance strongly through working with the better performers in the PRA activities.*

Result 2 is consistent with recent experimental research on information and learning. For example, He *et al.* (2022) experimentally showed that having information on others' answers helps less knowledgeable students to answer trivia questions correctly. Note that He *et al.* (2022) also showed that more knowledgeable students may perform less well by having information on others' answers when answering difficult questions. While the present experiment did not find evidence on such a harmful effect on better performers, it does not conflict with the finding by He *et al.* (2022) because the PRA questions should be (relatively) easy ones for the better performers (as they are designed to reinforce learning and not generally to extend it). Indeed, in He *et al.* (2022), having more information is not harmful to more knowledgeable students when the questions are easy ones.

While the average treatment effect was quite strong on the worse performers, one may wonder more precisely how their improvements depend on the sizes of intra-pair interim achievement differences. For example, if the abilities are too different among pair mates, improvements may be weak as they may not be able to effectively communicate with each other due to the lack of basic technical skills or fundamentally different work attitudes. Alternatively, the weaker the interim performance they have compared with the better performers, the worse performers may benefit more, considering that they have more room for improvement and also even worse performers have certain competency being admitted to the university based on the

[23] The number of students whose mark was exactly the median was only nine and therefore it is not meaningful to have another category where their interim mark was exactly the median in a regression. For this reason, the median subjects were simply included in the "below-median" set.

admission criteria.[24] This question can be examined by looking at the relationship between (a) student i's performance relative to their pair partner j's in the term 1 formative assessment (i.e., $x_i = f_i - f_j$) and (b) i's performance improvement gauged by the summative assessment relative to i's interim mark (i.e., $y_i = s_i - f_i$).[25]

Figure 4 reports the relationship by matching condition. Three interesting patterns emerge. First, the more behind a student was in the interim stage, the larger improvement (s)he achieved in the end through the term 2 PRA activities in the treatment condition (see the region where $x_i < 0$ in panel A). This resonates with the idea that peer learning is an effective way to improve the performance of poorer workers. This tendency is also seen for some small number of pairs in the control condition where intra-pair interim performance difference happened to be large despite the sorting process (see the region where $x_i < 0$ in panel B). Second, the peer-learning benefit of better performers did not depend on the size of the interim performance differences they had compared with their matched weak performers. In the region where $x_i > 0$ of panel A, the slope of the fitted curve becomes flatter as x becomes large. The small elasticity of the better performers' marks may be driven by a ceiling effect (the maximum mark is bounded above at 100). This also importantly means that forming pairs with larger ability differences would not hurt the better performers.[26] Third, and as anticipated, observations were more concentrated around $x_i = 0$, and the variation in y was much smaller in the control than in the treatment condition. Specifically, the standard errors (with seminar group clustering) were 2.414 and 1.568 marks in the treatment and control treatments, respectively. This suggests that the peer-learning effects are more homogeneous in the control than in the treatment condition.

The impact of the PRA activities can also be seen in the students' choices in the summative assessment. Students selected one of the two questions in Part B, and likewise in Part

[24] The students' pre-university data, such as A-level grades, were unavailable due to its confidentiality, making it impossible to study possible effects of pre-university achievement levels. Having said this, these background data were in any case not used in any aspect of the module. The unavailability of the data would also not affect the findings of the paper since seminar group allocations of students were random (footnote 7) and the background data were not required for pairing in the PRA activities. Due to the competitive nature of admission to Durham University, there is also considerable grade homogeneity at entry though not necessarily subject homogeneity.

[25] As noted in footnote 21, the absolute size of the summative mark (s_i) is not fully comparable to that of the term 1 formative mark (f_i), whose aspect makes the interpretation of the size of y_i difficult. However, y_i $\{= s_i - f_i\}$ is still a nuanced measure of academic improvement for across-subject comparisons. For example, given the value of f, the higher academic improvement a student has, the greater s and therefore the greater y a student has.

[26] As an anonymous reviewer pointed out, caution should be exercised on this point as better performers might have reduced performance through working with worse performers if the interim pair performance difference were too large. For $x_i \in [50, 100]$, a linear regression estimates that $y_i = -0.893(0.221)x_i + 57.510(17.622)$, where the numbers in parentheses are standard errors clustered by seminar group. The estimated result, however, can be only suggestive as there are only seven observations in this range.

C. Among the two questions in each Part, one question came from the topics in the PRA, while the other came from the topics in the formative. In Parts B and C of the summative assessment, strikingly, 98.0% and 91.6% of the students, respectively, selected questions whose topics were covered by the PRAs (Figure 5.A). The high popularity of the PRA topics in the summative assessment is affected neither by the matching condition,[27] nor by the interim performance level of students.[28] Hence, the PRA activities are more effective in deepening the learning and/or enhancing their study motivations than the formatives that are simply marked by tutors.

Unlike similarly high popularity of the PRA topics across the matching conditions, a closer look at students' performances by the Parts reveals two interesting patterns (Figures 5.B and 5.C). First, the students in pairs with a great spread in abilities (treatment condition) performed markedly better in the long-run macro question in Part C, the topic of term 2 PRA, relative to those in pairs with similar interim performances (control condition).[29] It should be acknowledged that students' marks for the short-run macro question were not that different between the two conditions as seen in panel C, whose result might have been driven by its small sample size (panel A).

Second, and equally important, the positive effect of term 2 peer learning spills over to their learning of term 1 materials. Those in the treatment condition performed much more strongly in Part B than those in the control condition, whether they selected the consumer theory question (the topic in term 1 PRA) or the producer theory question (the topic in term 1 formative). Notice that each student had two PRA partners – one for term 1 activities, and the other for term 2 activities. There were no differences in the partner assignment procedure for the term 1 activities between the treatment and control conditions.

Lastly, students performed well in the short-answer questions in Part A of the summative assessment regardless of the matching condition: their average mark in Part A does not significantly differ by the matching condition (14.89 for the treatment condition; 14.61 for the

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[27] 97.6% of students in the random matching condition and 98.4% of students in the sorting condition selected the PRA topic in Part B. The difference in the percentage between the treatment and control is insignificant at two-sided $p = 0.6800$ according to a Fisher exact test. Similarly, 91.9% of students in the random matching condition and 90.6% of students in the sorting condition selected the PRA topic in Part C; and the difference in the percentage between the treatment and the control is insignificant at two-sided $p = 1.000$.

[28] 98.5% of better performers and 97.2% of worse performers selected the PRA topic in Part B. The difference in the percentage is insignificant at two-sided $p = 0.6578$ according to a Fisher exact test. Similarly, 89.5% of better performers and 94.4% of worse performers selected the PRA topic in Part C. The difference in the percentage is insignificant at two-sided $p = 0.2401$ according to a Fisher exact test.

[29] Consistent with columns I.i and II.i of Table 3, both the better and worse performers in the treatment condition marked higher than those in the control condition (Appendix Figure B.3), but an analysis in Table 4 below reveals that (a) this pattern is due to a selection bias and (b) the worse performers in the treatment condition are the ones that benefited from the PRA activities.

control condition). This means that students in both matching conditions likely put in sufficient effort, being able to grasp the basic concepts and applying the concepts to economic questions.

In order to formally study treatment effects on students' performances in Part B, and also in Part C, a Heckman selection model was estimated (Table 4). The dependent variable is either their performance in Part B (column I) or Part C (column II), and the independent variables are the same as those in Tables 2 and 3. The model was estimated without further splitting the data to those who selected Question 3 or 4 (Question 5 or 6) because the attempt here is to study the overall impact on their performance on the term 1 (term 2) materials. The estimation clearly shows that students performed better in the treatment than in the control condition for both Parts B and C – see the t2 random matching dummy variable. Consistent with Result 2, the positive effect under term 2 random matching was driven by an improved performance exhibited by the worse performer in the pairs – see columns I.iv and II.iv.

As a further robustness check, nevertheless, the same model was also estimated when using students' marks in the PRA materials, namely Question 3 (Question 5), as the dependent variable. It finds almost the same results as Table 4 – see Supplementary materials Table B.3.[30] Hence, it can be concluded that the spill-over effects of term 2 peer learning on term 1 materials are significant. The spill-over effects can be thought of as being driven indirectly by the worse performers' improved learning in the PRA discussions, and/or by their study habits reformed through the PRA experiences.

Result 3: *The students in the treatment condition performed better than those in the control condition not only for Part C but also for Part B of the summative assessment. This suggests that the positive treatment effects of pair heterogeneity through the term 2 PRA activities spillover to their learning of the term 1 materials.*

5. Conclusion

Using a randomized field experiment in a classroom, this paper found that exogenously pairing two individuals with different interim achievement levels leads to better overall performance through peer learning, compared with pairing together those whose achievements are similar to each other, even though average achievement levels at the interim stage were similar for the two kinds of peer groups. The positive impact of pair heterogeneity was driven by a strong performance improvement of the less able, rather than of the more able, in a pair. The

[30] Additional regressions were also performed to study the impact of term 2 random matching on the students' scores in the formative materials, i.e., Question 4 in Part B (Question 6 in Part C). However, the selection model was not able to be estimated due to a small number of selected data.

more able was also not hurt by being matched with the less able. This result is consistent with the bargaining and mutual learning hypotheses: more able workers not only impose productive norms for the sake of their teams, but they also teach less able workers (e.g., Ichniowski *et al.*, 1997; Hamilton *et al.*, 2003). This result is also consistent with the prediction from social effects. A detailed look at the data further revealed that the positive effect of peer learning activities in term 2 was not limited to their understanding of term 2 materials (macroeconomics), but it also spilled over to their understanding of term 1 materials (microeconomics). This underlines great importance in devising effective pairing when implementing human resource management practices such as communication, peer learning, and skill training in organizations.

The role of team heterogeneity is an active research agenda in the recent literature. Based on randomized field experiments, it suggests that while peer effects are stronger in teams with a greater spread in abilities, the positive effects tend to be limited to high-ability individuals in a large team since they endogenously choose to interact with like-minded high types (e.g., Carrell *et al.*, 2009; Carrell *et al.*, 2013; Lyle, 2009; Duflo *et al.*, 2011; Feld and Zölitz, 2017). The low-ability individuals are therefore hurt in such teams. This matching situation was modeled in the sorting condition of the present study. The random matching condition of this paper showed stronger work performance than the sorting condition, and the worst performer in the former *benefited* more than the better performer. With the smallest peer group size, each student had no choice but to interact with their assigned peer in a mandatory peer learning activity. In addition, each pair was given a pre-determined task for learning activities. This setup effectively prevented the less able from being excluded from the more able students in the module.

The finding from the present study has a policy implication on effective learning practices. As already discussed, sub-groups tend to endogenously emerge among like-minded peers when the peer group size is large and their skills and abilities are heterogeneous. While the present study suggests a simple solution, namely, forcedly pairing more able with less able individuals, the so-called “tracking” has been proposed to help enhance productivity in the literature to date. For example, using a clear field experiment in primary schools, Duflo *et al.* (2011) demonstrated that when students are divided into sections based on prior achievement levels, even those assigned to low-achievement peer groups can improve academic performance. They argue that teachers can better tailor their instruction levels and methods if students are sorted based on their academic skills. The finding of the present paper, nevertheless, suggests that the effect of such tracking may not be strong under certain conditions if peer learning is an important element to achieve a given goal.[31] The field experiment in this study suggests that the more able would effectively teach the less able if they are forced to be paired through a fair process, which results in a performance improvement of the latter. This kind of pairing can be nested and implemented in multiple activities in organizations. Such positive effects of heterogeneity cannot be obtained if low-achieving individuals are simply grouped together.

While the PRA activities, especially the ones under random matching, lead to an improvement in academic performance, it should be acknowledged that its impact on welfare (utilities) is ambiguous. For example, recent theoretical research by Feng *et al.* (2018) shows that having more neighbors causes labor supply to increase by reducing leisure time, because people then have more social comparison with others and they have preferences of "keeping up with the neighbors." Their theoretical model proves that the overall welfare can be lower. In the context of the present study, it is possible that peer learning may encourage students to study the materials of this specific module beyond their socially optimal levels by limiting leisure time, or maybe even sacrificing studies in other modules. It would also be more difficult to get a better grade due to competition if all put highest effort driven by their social comparison preferences. Although it is not possible to clarify the impact on welfare using the data of the current study, their overall welfare might have been diminished by the inclusion of the PRA activities. How peer learning in a module affects students' overall welfare remains for future research.

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[31] It may also be difficult for teachers to adjust their teaching methods in low-achievement peer groups under certain conditions because low-ability students tend to report higher levels of satisfaction with their teachers' pedagogical practices (Lavy *et al.*, 2012).

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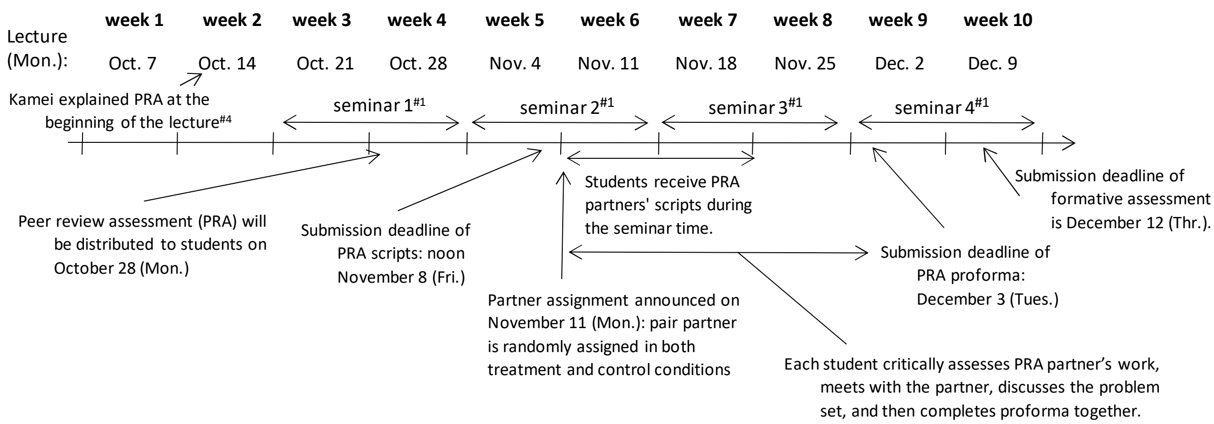
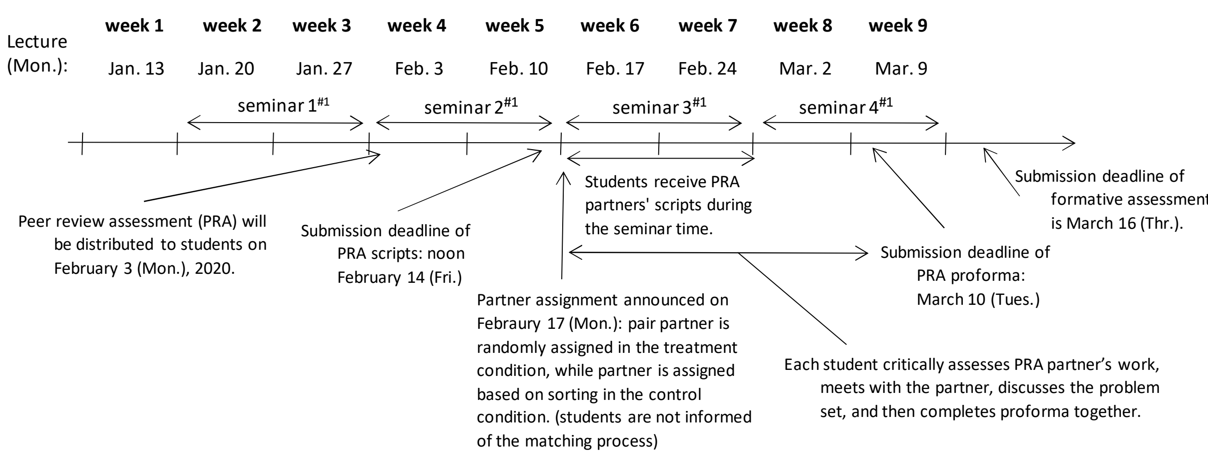
Figure 1: *Timeline of Peer Review Activities*

A. Term 1 (Microeconomics)[#2]

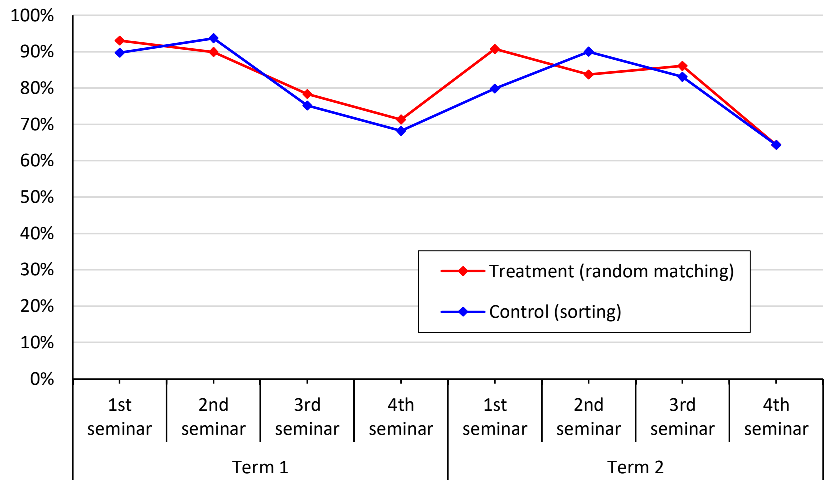


B. Term 2 (Macroeconomics)[#3]



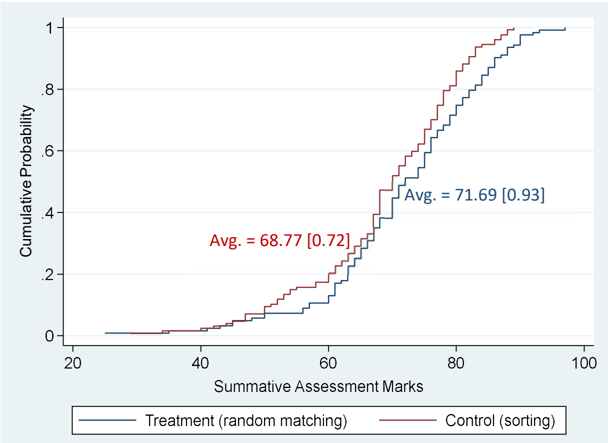
Notes: [#1] Each seminar is scheduled during a two-week window. The date of biweekly seminars (Monday, Tuesday or Thursday) differs by the seminar group, set by the undergraduate office. [#2] Students' conditions are identical for the treatment and control seminar groups in term 1. [#3] There is only one difference between the treatment and control groups in term 2. In a control seminar group, students are sorted in descending order according to term 1 formative marks; two students with the closest marks are paired. By contrast, in a treatment group, students are randomly broken into pairs for the peer review activities irrespective of their term 1 formative mark. [#4] As discussed, another faculty member was responsible for the lecturing in term 1. PRA was explained by Kamei using the materials in Supplementary materials A.1 at the onset of the second lecture in term 1.

Figure 2: *Trends of Average Seminar Attendance Rates*

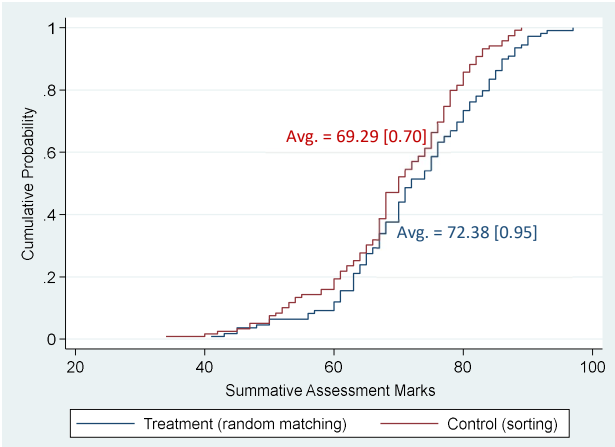


Note: The attendance rates were calculated based on eligible students (those who gave consent).

Figure 3: *Distribution of Students' Summative Assessment Marks*



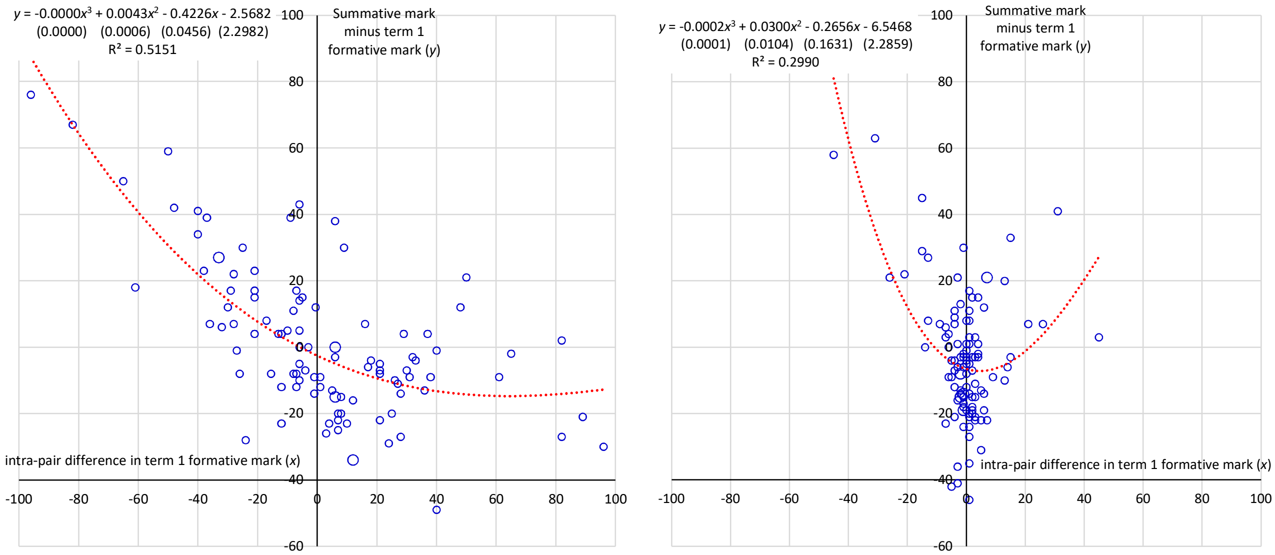
(A) All eligible students in the subject pool



(B) Students who submitted term 2 PRA and whose partner also submitted the assessment

Notes: The numbers in squared brackets are standard errors clustered by seminar group ID. The number of eligible observations in panel A is not the same as the size of the subject pool since a small number of students did not complete the summative assessments (Table 1).

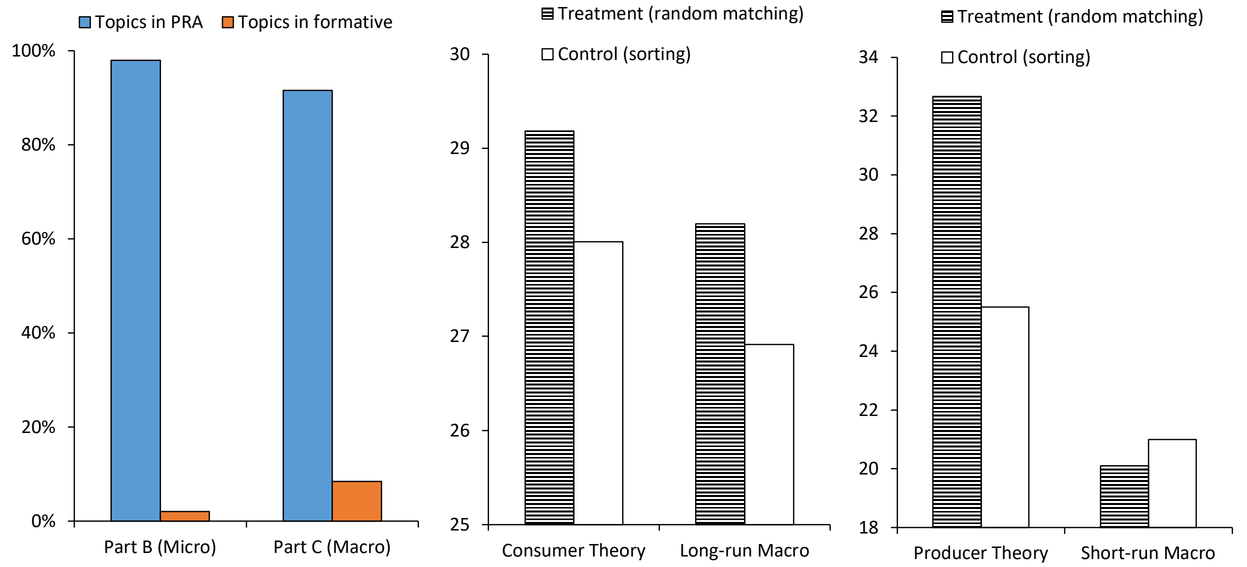
Figure 4: *Interim Achievement Differences and Improvement of Performances*



(A) Treatment condition (random matching) (B) Control condition (sorting)

Notes: The size of each point indicates its frequency. Almost all points have the frequency of one (i.e., one student). The numbers in parentheses in the polynomial equations in the figures are robust standard errors clustered by seminar group ID.

Figure 5: *Students' Decisions to Select Questions and Performances in the Summative Assessment*



(A) Distribution of students' selection (B) Avg. marks for topics in PRAs (C) Avg. marks for topics in formatives

Notes: The maximum mark in each part is 40. The topics in the PRAs are the consumer theory (term 1) and long-run macroeconomics (term 2). The topics in the formatives are the producer theory (term 1) and short-run macroeconomics (term 2). As in other analyses, those who gave consent and completed the summative assessment were used to calculate the distributions of problem selection and average marks.

Table 1: *Summary of Conditions*

Treatment	A. Treatment condition (Random matching)	B. Control condition (Sorting)	C. Total	Two-sided *p* for H_0: A = B[#5]
a. Number of seminar groups	8	8	16	---
b. Total number of students[#2]	139[#1]	139	278	---
c. Students who gave consent (subject pool)				
c.i. Number of the students	129 (92.8%)	130 (93.5%)	259 (93.2%)	---
c.ii. Number of female students out of c.i	59	72	131	0.1365
c.iii. Number of British students out of c.i	44	33	77	0.1363
c.iv. Number of those who submitted term 1 formatives out of c.i	122 (87.8%)	121 (87.1%)	243 (87.5%)	---
c.v. Avg. term 1 formative mark (out of 100) [#3,#4]	70.38	72.05	71.21	0.721
c.vi. Number of those who submitted summative assessments out of c.i	123 (95.4%)	127 (97.7%)	250 (96.5%)	---
c.vii. Number of those who submitted summative assessments out of c.iv	116 (83.5%)	118 (84.9%)	234 (84.2%)	---
c.viii. Avg. term 1 formative mark for c.vii[#3]	70.84	71.71	71.28	0.867

Notes: [#1] The number of the students was 142 at the beginning of term 2 when treatment allocations were made. Three students in the treatment condition were, however, not assigned any pair partners because one student requested exemption from the activity due to disability, another was found to have been suspended from the university (this student was not able to attend any academic activities in term 2), and the other withdrew from the module at the beginning of term 2. [#2] When the number of students in a given seminar group was odd, one interaction unit was a three-student team where PRA scripts were swapped among them. [#3] The cumulative distributions of formative assessment marks can be found in Supplementary materials Section B.1. [#4] The average term 2 formative marks were similar for the two conditions (60.4 in the treatment condition; and 59.6 in the control condition). It should be worth noting that students were distributed, and started to work on, the term 2 formative assessment on February 24, 2020, which was before the peer review assessment activities were completed. Hence, it is not surprising to see no effects of the treatment interventions on term 2 formative performances. [#5] Fisher's exact tests for rows c.ii and c.iii, and Somers' D with seminar group clustering for rows c.v and c.viii.

Table 2: *Treatment Effects of Term 2 Random Matching*

(A) Second Stage Regression (Treatment effect)

Dependent variable: Summative assessment mark of student *i*

Data:	(I) All data		(II) Both *i* and *i*'s partner submitted term 2 PRAs	
Independent variable:	(i)	(ii)	(i)	(ii)
(a) t2 random matching dummy {=1(0) for the treatment (control) condition}	3.10*** (1.19)	3.30*** (1.03)	2.43** (1.16)	2.50** (1.02)
(b) A dummy that equals 1 if *i* did not submit term 1 formative assessment	---	4.26 (5.80)	---	6.20 (6.55)
(c) Interaction term: (1 – variable (b)) × term 1 formative assessment mark	---	0.16*** (0.040)	---	0.16*** (0.05)
A three-student team dummy {= 1(0) if a student was assigned to a three(two)-student team}	-6.13* (3.45)	-0.89 (3.47)	-4.50 (4.00)	0.30 (4.03)
Constant	70.15*** (1.62)	59.54*** (3.00)	70.39*** (1.09)	59.51*** (3.35)
# observations	259	259	236	236
# selected	250	250	228	229
Log pseudolikelihood	-1005.01	-995.13	-906.96	-902.24

(B) Selection equation that explains whether student *i* submits the summative assessment (i.e., the submission is observed)

Data:	(I) All data		(II) Both *i* and *i*'s partner submitted term 2 PRAs	
Independent variable:	(i)	(ii)	(i)	(ii)
(a) t2 random matching dummy {=1(0) for the treatment (control) condition}	0.04 (0.09)	0.17** (0.08)	-0.21 (0.33)	-0.15 (0.29)
(b) A dummy that equals 1 if *i* did not submit term 1 formative assessment	---	5.09 (n.a.)	---	4.87 (3.15)
(c) Interaction term: (1 – variable (b)) × term 1 formative assessment mark	---	0.002 (0.003)	---	0.005 (0.01)
(d) The number of formative assessments not submitted {= 0, 1, 2}	-0.61*** (0.03)	-0.36*** (0.02)	-0.60** (0.29)	-0.86* (0.47)
(e) Seminar attendance rate ∈ [0, 1]	0.23*** (0.01)	0.50*** (0.02)	0.18 (0.68)	0.28 (0.71)
A three-student team dummy {= 1(0) if a student was assigned to a three(two)-student team}	0.09 (0.27)	4.15 (n.a.)	4.70*** (0.86)	4.14** (1.86)
Constant	1.80*** (0.14)	1.16*** (0.26)	2.28*** (0.62)	1.93*** (0.65)

Notes: Estimations of the Heckman two-stage selection model with robust standard errors clustered by seminar group ID. The numbers in parentheses are standard errors. In addition to the independent variables listed in the table, a term 1 tutor dummy was controlled in both stages of regressions since there were two seminar tutors in term 1. A three-student team dummy was also added as a control since there was one such team in a session whose number of students was odd. In columns II.i and II.ii, only observations in which a student submitted term 2 peer review assessment and their partner also submitted it were used as data. Equations I.i, I.ii, II.i, and II.ii of panel B are the selection equations of columns I.i, I.ii, II.i, and II.ii, respectively, of panel A. *, **, and *** indicate significance at the 0.10 level, at the 0.05 level and at the 0.01 level, respectively.

Table 3: *Mechanism behind the Positive Impact of Term 2 Random Matching*

(A) Second Stage Regression

Dependent variable: Summative assessment mark of student *i*

Data:	(I) All data		(II) Both *i* and *i*'s partner submitted term 2 PRAs	
Independent variable:	(i)	(ii)	(i)	(ii)
(a) Better performer dummy: $\mathbf{1}\{x_i > x_j, \text{random matching}\}$[#1]	1.67*	0.08	2.48**	0.27
	(-.89)	(0.97)	(1.05)	(1.22)
(b) Worse performer dummy: $\mathbf{1}\{x_i < x_j, \text{random matching}\}$[#2]	2.78*	5.34***	2.56	3.64**
	(1.54)	(1.65)	(1.57)	(1.72)
(c) Term 1 formative assessment mark (x_i)	---	0.20***	---	0.19***
		(0.05)		(0.06)
A three-student team dummy {= 1(0) if a student was assigned to a three(two)-student team}	-6.67	0.42	-5.94	0.89
	(4.70)	(3.76)	(5.19)	(4.54)
Constant	71.06***	57.53***	71.36***	57.83***
	(1.18)	(3.58)	(1.15)	(3.90)
# observations	243	243	226	226
# selected	234	234	218	218
Log pseudolikelihood	-935.95	-926.36	-858.79	-859.79

(B) Selection equation that explains whether student *i* submits the summative assessment (i.e., the submission is observed)

Data:	(I) All data		(II) Both *i* and *i*'s partner submitted term 2 PRAs	
Independent variable:	(i)	(ii)	(i)	(ii)
(a) Better performer dummy: $\mathbf{1}\{x_i > x_j, \text{random matching}\}$[#1]	-0.38***	-0.24*	-0.44***	-0.42
	(0.08)	(0.13)	(0.10)	(0.53)
(b) Worse performer dummy: $\mathbf{1}\{x_i < x_j, \text{random matching}\}$[#2]	0.12	-0.08	0.12	0.14
	(0.12)	(0.17)	(0.13)	(0.40)
(c) Term 1 formative assessment mark (x_i)	---	-0.006	---	0.010
		(0.006)		(0.014)
(d) The number of formative assessments not submitted {= 0, 1, 2}	-0.57***	-0.51***	-.69***	-1.02**
	(0.03)	(0.14)	(0.04)	(0.50)
(e) Seminar attendance rate $\in [0, 1]$	0.24***	0.41***	0.81***	0.31
	(0.01)	(0.09)	(0.05)	(0.65)
A three-student team dummy {= 1(0) if a student was assigned to a three(two)-student team}	0.13	n.a.[#3]	3.81	3.25
	(0.37)		(n.a.)	(3.39)
Constant	1.71***	1.95***	1.42***	1.69***
	(0.14)	(0.65)	(0.15)	(0.95)

Notes: Estimations of the Heckman two-stage selection model with robust standard errors clustered by seminar group ID. The numbers in parentheses are standard errors. In addition to the independent variables listed in the table, a term 1 tutor dummy was controlled in both stages of regressions since there were two seminar tutors in term 1. Only observations in which a student submitted term 1 formative and their partner also submitted it were used as data. A three-student team dummy was also added as a control since there was one such team in a session whose number of students was odd. [#1] $\mathbf{1}\{x_i > x_j, \text{random matching}\}$ is an indicator variable which equals 1 if $x_i > x_j$ and *i* is in the treatment condition; 0 otherwise. Here, x_i (x_j) is *i*'s (*i*'s partner *j*'s) term 1 formative assessment mark [#2] $\mathbf{1}\{x_i < x_j, \text{random matching}\}$ is an indicator variable which equals 1 if $x_i < x_j$ and *i* is in the treatment condition; 0 otherwise. The reference group is observations in the control condition. Equations I.i, I.ii, II.i, and II.ii of panel B are the selection equations of columns I.i, I.ii, II.i, and II.ii, respectively, of panel A. [#3] The three-student team dummy was not included in the selection equation since otherwise the model was not converged. *, **, and *** indicate significance at the 0.10 level, at the 0.05 level and at the 0.01 level, respectively.

Table 4: *The Impact of Term 2 Random Matching by Part in the Summative Assessment*

(A) Second Stage Regression

Dependent variable:	(I) Mark of student *i* in Part B (Micro)				(II) Mark of student *i* in Part C (Macro)			
Independent variable:	(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
(a) t2 random matching dummy {=1(0) for the treatment (control) condition}	1.49** (0.75)	1.62** (0.65)	---	---	1.35** (0.55)	1.01* (0.57)	---	---
(b) A dummy that equals 1 if *i* did not submit term 1 formative assessment	---	3.77 (2.84)	---	---	---	-0.20 (3.55)	---	---
(c) Interaction term: (1 – variable (b)) × term 1 formative assessment mark	---	0.08*** (0.02)	---	---	---	0.05** (0.02)	---	---
(d) Better performer dummy: **1**{$x_i > x_j$, random matching}[#1]	---	---	1.14** (0.49)	0.32 (0.47)	---	---	0.01 (0.65)	-0.21 (0.66)
(e) Worse performer dummy: **1**{$x_i < x_j$, random matching}[#2]	---	---	1.20 (1.07)	2.27** (1.02)	---	---	0.95 (0.82)	2.19*** (0.85)
(f) Term 1 formative assessment mark (x_i)	---	---	---	0.09*** (0.03)	---	---	---	0.06*** (0.02)
A three-student team dummy {= 1(0) if a student was assigned to a three(two)-student team}	-0.35 (2.12)	1.98 (1.92)	-0.96 (2.54)	1.71 (2.15)	-4.03*** (1.10)	-1.58 (1.65)	-3.37 (2.19)	-2.24 (2.21)
Constant	28.72*** (0.73)	23.14*** (1.64)	28.94*** (0.48)	22.59*** (1.98)	26.98*** (0.53)	23.68*** (1.52)	27.53*** (0.62)	23.79*** (1.74)
# observations	259	259	243	243	259	259	243	243
# selected	250	250	234	234	250	250	234	234
Log pseudolikelihood	-870.62	-863.83	-815.16	-807.72	-827.49	-835.17	-777.63	-761.32

(B) Selection equation that explains whether *i* submits the summative assessment (i.e., the submission is observed)

Dependent variable:	(I) Mark of student *i* in Part B (Micro)				(II) Mark of student *i* in Part C (Macro)			
Independent variable:	(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
(a) t2 random matching dummy {=1(0) for the treatment (control) condition}	-0.20* (0.11)	0.001 (0.09)	---	---	0.26*** (0.08)	0.32 (0.27)	---	---
(b) A dummy that equals 1 if *i* did not submit term 1 formative assessment	---	0.26 (0.39)	---	---	---	6.32*** (0.88)	---	---
(c) Interaction term: (1 – variable (b)) × term 1 formative assessment mark	---	0.001 (0.003)	---	---	---	0.004 (0.01)	---	---
(d) Better performer dummy: **1**{$x_i > x_j$, random matching}[#1]	---	---	-0.17*** (0.06)	-0.24 (1.15)	---	---	-0.38 (0.35)	-0.03 (0.11)
(e) Worse performer dummy: **1**{$x_i < x_j$, random matching}[#2]	---	---	-0.05 (0.14)	-0.23 (0.48)	---	---	-0.37 (0.41)	-0.46 (0.14)
(f) Term 1 formative assessment mark (x_i)	---	---	---	0.00 (0.02)	---	---	---	0.003 (0.004)
(g) The number of formative assessments not submitted {= 0, 1, 2}	-0.27*** (0.01)	-0.28*** (0.01)	-0.40*** (0.02)	-0.47 (0.96)	-0.16*** (0.01)	-0.55* (0.29)	-0.54** (0.27)	-0.58*** (0.04)
(h) Seminar attendance rate ∈ [0, 1]	0.00 (0.00)	-0.26*** (0.010)	-0.13*** (0.01)	-0.08 (0.09)	0.00 (0.00)	0.05 (0.65)	0.09 (0.59)	0.61*** (0.04)
A three-student team dummy {= 1(0) if a student was assigned to a three(two)-student team}	-0.086 (0.28)	-0.036 (0.26)	2.70 (n.a.)	3.85 (n.a.)	4.45 (n.a.)	6.04*** (0.35)	4.78*** (0.47)	6.52 (n.a.)
Constant	1.76*** (0.12)	1.76*** (0.22)	1.85*** (0.10)	1.99*** (0.29)	1.26*** (0.10)	2.00*** (0.52)	2.25*** (0.52)	0.83*** (0.29)

Notes: Estimations of the Heckman two-stage selection model with robust standard errors clustered by seminar group ID. The numbers in parentheses are standard errors. All data are used. In addition to the independent variables listed in the table, a term 1 tutor dummy was controlled in both stages of regressions since there were two seminar tutors in term 1. For columns I.iii, I.iv, II.iii, and II.iv, only observations in which a student submitted term 1 formative and their partner also submitted it were used as data. [#1] **1**{$x_i > x_j$, random matching} is an indicator variable which equals 1 if $x_i > x_j$ and *i* is in the treatment condition; 0 otherwise. Here, x_i (x_j) is *i*'s (*i*'s partner *j*'s) term 1 formative assessment mark [#2] **1**{$x_i < x_j$, random matching} is an indicator variable which equals 1 if $x_i < x_j$ and *i* is in the treatment condition; 0 otherwise. Equations I.i, I.ii, I.iii, I.iv, II.i, II.ii, II.iii and II.iv of panel B are the selection equations of columns I.i, I.ii, I.iii, I.iv, II.i, II.ii, II.iii and II.iv, respectively, of panel A. Results change little when the demographic information is added as controls. *, **, and *** indicate significance at the 0.10 level, at the 0.05 level and at the 0.01 level, respectively.

Online Supplementary Materials for Kamei and Ashworth:

“Peer Learning in Teams and Work Performance:

Evidence from a Randomized Field Experiment.”

This Supplementary materials include experimental procedure, and additional figures and tables that supplements Kamei and Ashworth.

Table of Contents

Section A. Experimental Procedure

A.1 Descriptions of Peer Review Assessment to Students

Kamei explained the requirements and the logistics of peer review assessment at the beginning of the lecture in the ECON1101 module on October 14, 2019. Students were not told that they were participating in the experiment. The following documents were distributed and explained to the students:

ECON1011: Introduction to Economics

Peer Review Assessment (PRA)

Kenju Kamei (module leader)

A. The Aim:

- To help students understand the course material and its applications in a structured way, to consolidate your knowledge and to develop further relevant skills (the same purpose as the formative assessment).
- To provide students with an opportunity to learn how to interact and discuss with others. There are many occasions in which you will need to collaborate with people you may not know very well in daily life or workplace setting. Fostering collaborative skills is as useful as gaining knowledge and skills. For this reason, your peer review partner will be assigned (you cannot choose who to be paired with). The pairing changes from term I to term II. You will be informed of your partner's name in the middle of each term.
- To provide students with an opportunity to learn how to assess others' works and build their critical assessment skills.

B. The Topic:

- As written in the module handbook, you will be assigned a problem set, whose format is the same as the formative assessment. (Thus, you have two assessment work per term.)
- The topic of PRA is different from that of the formative assessment. We aim to cover two major topics in each term with the two assessments as follows so that these two assessments help you prepare for the summative assessment:

  a. Term I:
  PRA: *Consumption theory*
  Formative: *Production theory*

  b. Term II:
  PRA: *Long-run macroeconomics (Solow model)*
  Formative: *Short-run macroeconomics (Keynesian Cross, IS-LM model)*

- Both the peer review assessment and the formative assessment are a part of important academic commitment.

C. Timeframe and activities:

- Each student will be assigned a problem set and should first answer the question by themselves. The problem set will be given to students around 10 days prior to its due date. For example, the problem set in term I is distributed to student on the **28th October (Monday)**. The due date of your submission is **noon Friday 8th November** in the 5th teaching week in term I (**noon Wednesday 14th February** in the 15th teaching week in term II). Please submit your solutions to the undergraduate office. Note that electronic submissions are NOT allowed.

  # In your PRA, please make sure to write **your full name**, **seminar group number** and **the name of seminar tutor** so that your tutor can collect your assessment from the undergraduate office and give it to your correct partner in your seminar group.

- You will be informed of who your assessment partner is on DUO on the 11th November in term I (17th February in term II).
- You will receive the PRA partner's submission in teaching week 6 or 7 (11 November to 22 November) in term I, and in teaching week 16 or 17 (17 February to 28 February) in term II. Your seminar tutor will give your partner's PRA to you. Note that partner assignment to you may change in case that your partner does not submit his/her assessment. Please make sure to collect your partner's assessment in the tutor's office hours in event that you miss the seminar in week 6 or 7 [cf. See the mandatory attendance policy for seminars: you are required to meet your seminar tutor at his/her consultation hours if you fail to attend a seminar].
- **You will critically assess your partner's submission by filling in the proforma (the proforma is included at the end of this document). After that, you will need to meet with your partner, will discuss the parts for improvement, and will write what you learned from your partner's critical assessment on the proforma**.

  We recommend you to meet with your partner by Friday 29 November 2019 in term I (by 6 March 2020 in term II) and must submit the proforma by 3rd December (10 March) to the undergraduate office. You will need to discuss with your peer partner and arrange the date to meet – we suggest you to discuss the meeting plan immediately after you receive your partner's assessment in a seminar. The module team will check who submitted proforma [note that your seminar tutor will not mark proforma since this is a critical assessment within pairs].

- Once all seminar groups completed the peer review assessment process, we will post the solutions to DUO (i.e., for example, after 3rd December in term I).
- Appendix at the end of this document includes the timeframe of the PRA process.

Remark 1: There is no peer evaluation process for the formative assessment. You need to attempt the formative assessment individually. After you submit your formative, your seminar tutor marks it and give feedbacks to you. After you submit your formative, you are very welcome to discussing the formative assessment or any materials towards the exam with your PRA partners.

Remark 2: Peer review assessment is not marked by your seminar tutor. You can learn how to assess or mark the answer based on your tutor's marking & feedback for the formative assessment.

PROFORMA: Peer Review Assessment

Introduction to Economics (ECON1011)

Your Number: ____________________

PRA Partner's Name: ________________

Seminar Group: _______________

Seminar Tutor's Name: _______________

In assessing your partner's work, please note that each question should have three components: (a) explanation of approach, (b) correct calculations/diagrams, and (c) interpretation of the answer. For each question, complete Part A.

After you finish assessing your PRA partner's work, you need to meet with your PRA partner for discussions. In the meeting, please give the printed cover sheet (this page) and proforma to the partner and discuss your critical assessment. Through the discussion, please reach an agreement on mark and write an agreed mark between you and your partner in Part C.

Your partner will also complete Part B immediately after the meeting and submits the form to the undergraduate office.

Meeting date with your partner: __________________

Example: Each question has one page that consists of Parts A to C

Question (a)

Part A: Assessment of your PRA partner's work:

- Complete before meeting
- Use bullet points

Your subjective mark for the partner's work: ________

Please give a mark based on your subjective judgment.

Please write any critical assessment in this box

Part B: What you learn from the discussions:

- Complete immediately after the meeting.
- Bullet points allowed.

Please write anything you learn (e.g., area for improvement) in this box

Part C: Agreed mark: _______

Appendix: Schedule

Term I

Peer review assessment will be distributed to students on 28 Oct. (Mon)

Week 11	Mon 30 Sep - Fri 04 Oct	Michaelmas	Induction Week
Week 12	Mon 07 Oct - Fri 11 Oct	Michaelmas	Teaching week 1
Week 13	Mon 14 Oct - Fri 18 Oct	Michaelmas	Teaching week 2
Week 14	Mon 21 Oct - Fri 25 Oct	Michaelmas	Teaching week 3
Week 15	Mon 28 Oct - Fri 01 Nov	Michaelmas	Teaching week 4
Week 16	Mon 04 Nov - Fri 08 Nov	Michaelmas	Teaching week 5
Week 17	Mon 11 Nov - Fri 15 Nov	Michaelmas	Teaching week 6
Week 18	Mon 18 Nov - Fri 22 Nov	Michaelmas	Teaching week 7
Week 19	Mon 25 Nov - Fri 29 Nov	Michaelmas	Teaching week 8
Week 20	Mon 02 Dec - Fri 06 Dec	Michaelmas	Teaching week 9
Week 21	Mon 09 Dec - Fri 13 Dec	Michaelmas	Teaching week 10

Deadline of PRA submission: noon Fri. 8th Nov.

Partner assignment announced on 11th Nov.

You will receive your PRA partner's work in the seminar.

Critically assess PRA partner's work and meet with the partner. Deadline of completed proforma to the undergraduate office is 3rd Dec (Tuesday). We recommend you to have a meeting by 29 Nov.

FYI: Deadline of formative assessment is Thursday 12 December.

Term II

Peer review assessment will be distributed to students on 3 Feb. (Mon)

Week 26	Mon 13 Jan - Fri 17 Jan	Epiphany	Teaching week 11
Week 27	Mon 20 Jan - Fri 24 Jan	Epiphany	Teaching week 12
Week 28	Mon 27 Jan - Fri 31 Jan	Epiphany	Teaching week 13
Week 29	Mon 03 Feb - Fri 07 Feb	Epiphany	Teaching week 14
Week 30	Mon 10 Feb - Fri 14 Feb	Epiphany	Teaching week 15
Week 31	Mon 17 Feb - Fri 21 Feb	Epiphany	Teaching week 16
Week 32	Mon 24 Feb - Fri 28 Feb	Epiphany	Teaching week 17
Week 33	Mon 02 Mar - Fri 06 Mar	Epiphany	Teaching week 18
Week 34	Mon 09 Mar - Fri 13 Mar	Epiphany	Teaching week 19
Week 35	Mon 16 Mar - Fri 20 Mar	Epiphany	Teaching week 20

Deadline of PRA submission: noon Fri. 14th Feb.

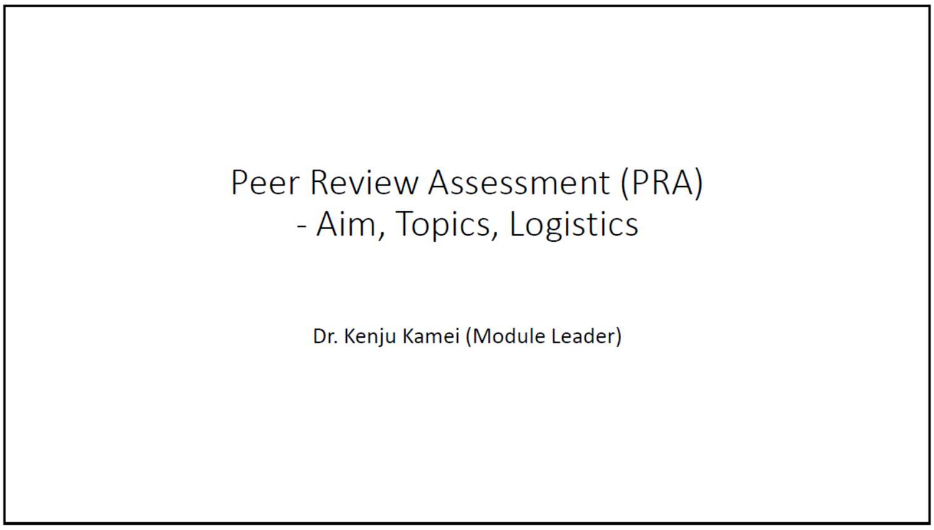
Partner assignment announced on 17th Feb.

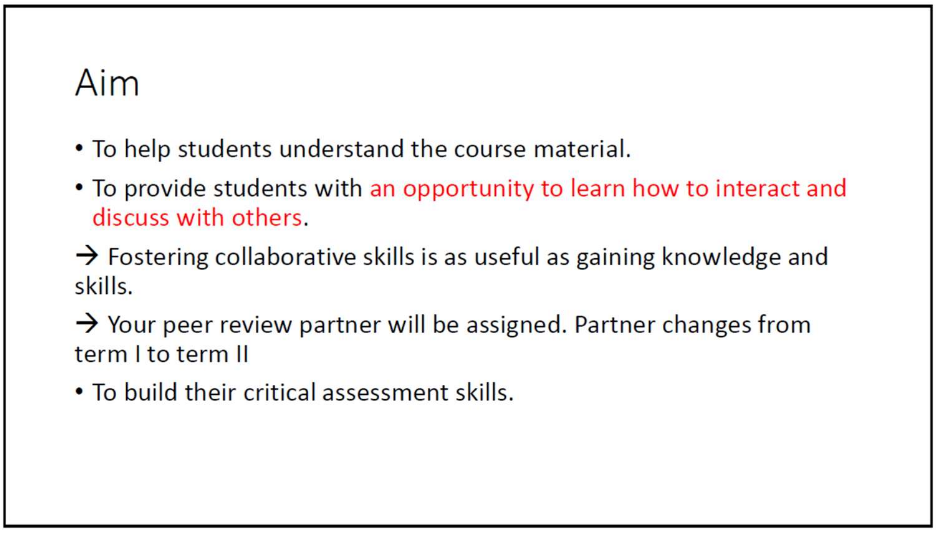
You will receive your PRA partner's work in these weeks.

Critically assess PRA partner's work and meet with the partner. Deadline of completed proforma to the undergraduate office is 10th March (Tuesday). We recommend you to have a meeting by 6 March.

FYI: Deadline of formative assessment is Thursday 16 December.

The following PowerPoint slides were also used to explain the aim of peer review assessment to students on October 14, 2019:





Topics

- Two assessments in each term.
- Term I
  - PRA: *Consumption Theory*
  - Formative assessment: *Production Theory*
- Term II
  - PRA: *Long-run macroeconomics*
  - Formative assessment: *Short-run macroeconomics*

❑ Academic commitments

Timeframe for Term I (PRA happens in the same timing in Term II)

- A problem set for PRA is distributed on DUO immediately after the lecture on 28th October (Monday).
- Due date: **noon Friday 8th November** to Undergraduate office.

Remark: Electronic submissions are NOT Allowed.

- Your pair partner will be announced on Monday 11th November.
- In following seminars (11 November to 22 November), you will receive your partner's work by your seminar tutor.
- You will **(a) critically assess your partner's submission by filling in the proforma, and** need to **(b) meet with the partner, discussing your assessment**.

Timeframe for Term I (PRA happens in the same timing in Term II)

- Discuss a meeting plan immediately after the relevant seminar is over (immediately after you receive your partner's work).
- Once the peer review process is over, return the proforma to the undergraduate office by **3rd December**.
- See an example of proforma in description file.

A.2. Term 1 Peer Review Assessment

Term 1 lectures were delivered by another staff member in the module team. Each student was randomly paired with another student in their seminar group, and engaged in the peer review assessment activities based on the following problem set prepared by the staff member. As explained in the paper, the staff member was not informed of the experiment. The staff independently prepared for the problem set for the peer review assessment, following the module requirement set by Kamei (the module leader for ECON1101).

Submission deadline: November 8th 2019 at noon

Peter and Jane are utility-maximisers and they have both an income of 20 pound, which must be allocated between beer (good 1) and pizza (good 2). It is known that the price of a bottle of beer is 2 pound and the price of a pizza is 6 pound.

Peter has diminishing marginal rate of substitution for the two goods. His marginal rate of substitution is: $MRS(q_B, q_P) = \left(\frac{q_P}{q_B}\right)^{\frac{1}{2}}$. Jane's utility function is instead $U(q_B, q_P) = \min(q_B, 2q_P)$.

For each consumer, answer the following questions:

(i) Calculate the optimal quantity of beer and pizza and show it in a diagram. (40 marks)

(ii) Now suppose that the price of beer decreases to 1 pound. Calculate the impact of the fall in the price of beer on the optimal demand of the two goods, show the effect in a diagram and comment. (20 marks)

(iii) Show the substitution and income effects in a diagram and comment. (20 marks)

(iv) On the basis of your analysis, draw the demand curve for beer and the effect of the fall in the price of beer on the demand for pizzas. (20 marks)

A.3. Term 1 Formative Assessment

16 seminar groups were randomly assigned to either the treatment condition or the control condition immediately before the peer review assessment in term 2. Pairs were randomly formed based on computer random-number generators in each treatment group, while students in the control condition were sorted according to their term 1 formative assessment marks in their own seminar group and then their pairs were assigned. The term 1 formative assessment can be found below. Regardless of the treatment condition, every student was asked to solve the problem independently as a requirement of ECON1101. The problem set was prepared by the staff member who delivered the term 1 lectures. As noted in Section A.2, this staff member did not know the presence of the experiment; she instead performed the teaching duty following the module handbook and requirement set by Kamei.

Firms A and B both use capital and (unskilled) labour as factors of production. Firm A has a Cobb-Douglas production function: $q = K^{\alpha}L^{\beta}$. This implies the marginal rate of (technical) substitution is: $MRS = \frac{\beta K}{\alpha L}$. Let us assume that $\alpha = 0.8$ and $\beta = 0.2$. Firm B has instead the following technology: $q = 6K + 4L$. Wages are equal to 10,000 £ and the cost of capital is also equal to 10,000 £.

For each firm, answer the following questions:

(i) Calculate the optimal quantity of capital and labour, show the solution in a diagram and comment. (40 marks)

(ii) Derive the total cost function, draw it in a diagram and comment on the shape. (10 marks)

(iii) Derive the average and the marginal cost functions. (10 marks)

(iv) Now suppose that the price of capital increases to 15,000 £. Calculate the impact of the increase in the price of capital on the optimal demand for capital and labour, show the effect in a diagram and comment. (25 marks)

(v) Show how the total cost function changes following the increase in the price of capital. (10 marks)

(vi) What is the impact on the average and the marginal cost of production? (5 marks)

Note: The deadline for submissions was December 12, 2019.

A.4. Term 2 Peer Review Assessment

The following includes the peer review assessment for term 2. As explained, the pairing process differed between the treatment and control conditions.

Suppose that a country is described as a closed economy and has the following production function:

$$Y = F(K, L) = 3K^{3/4}L^{1/4},$$

where K is the amount of capital, and L is the amount of labour hours.

(a) What is the per worker production function, $y = f(k)$, in this country? Here, k is defined as K/L. What is the equation of motion for k? Carefully explain how you obtain the equation. (10 points)

(b) Suppose that the annual saving rate is 20% ($s = .20$) and 5% of capital depreciates in each year ($\delta = .05$). Solve the steady-state values of k, y, and c (per worker consumption). Explain why the values you find are steady-state values using a diagram. Explain also the relationship between the saving rates and steady-state values of k. (25 points)

(c) Explain carefully what the Golden-rule steady state is in macroeconomics (you can use both graphs and algebra). (20 points)

(d) Calculate the Golden-rule per worker capital level k, and per worker consumption, assuming that $\delta = .05$. Which level of saving rate leads to this Golden-rule steady state? (25 points) Hint: $dk^{\alpha}/dk = \alpha k^{\alpha-1}$

(e) Suppose that the country instead has the following production function:

$$Y = F(K, L) = 3K.$$

Explain what the steady state capital level is, assuming that the saving rate and the depreciation rate are the same as in question b ($s = .20$, $\delta = .05$). Explain also what the Golden-rule per worker capital level is for this production function, assuming that $\delta = .05$. (20 points).

Note: The deadline for submissions was 14 February 2020.

A.5. Term 2 Formative Assessment

The following includes the formative assessment for term 2. It includes a problem set on short-run macroeconomics.

Suppose that a country operates as a closed economy and that the economy is in a full-employment equilibrium. Answer the following questions.

(a) Explain carefully what the Keynesian multiplier effect is in macroeconomics. Mathematically derive the tax multiplier in the *very short run*. Explain mathematically how the tax multiplier changes if the country changes the system to an open economy. (30 points)

(b) Explain the size of tax multiplier in *the short run* and in *the long run*, respectively. As for the multiplier in the short run, you need to consider (a) the impact of price change and (b) that of the changes in interest rates, using appropriate diagrams. (20 points)

(c) Explain how the IS curve is derived using the Keynesian Cross diagram. (25 points)

(d) Carefully explain how the AD curve is derived from the IS-LM framework, using appropriate diagrams. (25 points)

Note: The deadline for submissions was March 16, 2020.

A.6. Proforma for Term 2 Peer Review Assessment

The following includes the proforma for term 2 in the peer review assessment activities. There are five forms since there are five questions in the problem set.

PROFORMA: Term 2 Peer Review Assessment

Introduction to Economics (ECON1011)

Your Number: ____________________

Your Name: ____________________

PRA Partner's Name: ________________

Seminar Group: _______________

In assessing your partner's work, please note that each question should have three components: (a) explanation of approach, (b) correct calculations/diagrams, and (c) interpretation of the answer. For each question, complete Part A.

After you finish assessing your PRA partner's work, you need to meet with your PRA partner for discussions. In the meeting, please give the printed cover sheet (this page) and proforma to the partner and discuss your critical assessment with the partner. Through the discussion, please reach an agreement on mark and write an agreed mark between you and your partner in Part C.

Your partner will also complete Part B immediately after the meeting and submits the form to the undergraduate office. The deadline of submission is noon 10 March.

Meeting date with your partner: __________________

Question (a) – Maximum is 10 marks

Part A: Assessment of your PRA partner's work: **- Complete before meeting** **- Use bullet points** Your subjective mark for the partner's work: _______
Part B: What you learn from the discussions: **- Complete immediately after the meeting.** **- Bullet points allowed.**
Part C: Agreed mark: _______

Question (b) – Maximum is 25 marks

Part A: Assessment of your PRA partner's work: **- Complete before meeting** **- Use bullet points** Your subjective mark for the partner's work: _______
Part B: What you learn from the discussions: **- Complete immediately after the meeting.** **- Bullet points allowed.**
Part C: Agreed mark: _______

Question (c) – Maximum is 20 marks

Part A: Assessment of your PRA partner's work: **- Complete before meeting** **- Use bullet points** Your subjective mark for the partner's work: _______
Part B: What you learn from the discussions: **- Complete immediately after the meeting.** **- Bullet points allowed.**
Part C: Agreed mark: _______

Question (d) – Maximum is 25 marks

Part A: Assessment of your PRA partner's work: **- Complete before meeting** **- Use bullet points** Your subjective mark for the partner's work: _______
Part B: What you learn from the discussions: **- Complete immediately after the meeting.** **- Bullet points allowed.**
Part C: Agreed mark: _______

Question (e) – Maximum is 20 marks

Part A: Assessment of your PRA partner's work: **- Complete before meeting** **- Use bullet points** Your subjective mark for the partner's work: _______
Part B: What you learn from the discussions: **- Complete immediately after the meeting.** **- Bullet points allowed.**
Part C: Agreed mark: _______

A.7. Summative Assessment

The instructions to students:

Answer ALL questions in Section A, this accounts for 20% of the overall mark.

Answer ONE question from Section B, this accounts for 40% of the overall mark.

Answer ONE question from Section C, this accounts for 40% of the overall mark.

SECTION A
Answer both parts of both questions.

1. Consider the market for cars assuming that the demand curve is perfectly elastic. The government decides to give a subsidy to car producers.

(i) What is the impact on the price and the quantity produced in the market? (50 marks)

(ii) Show the distributional effects of the policy in terms of changes in surplus and the deadweight loss (if any) that the policy would generate. (50 marks)

2. Answer the following questions in macroeconomics.

(i) Define and explain the concepts of the GDP deflator and consumer price index. Explain how these two price indices differ from each other. (50 marks)

(ii) Suppose that there are only good A and good B in a given country. The price and quantity in 2006 and 2007 are provided in the following table:

	2006		2007	
	P	Q	P	Q
Good A	£20	800	£25	1,000
Good B	£30	252	£5	152

Calculate the GDP deflator in 2006 and 2007, assuming that the base (reference) year is 2006. Calculate also the inflation rate from 2006 to 2007. (50 marks)

SECTION B
Answer one question.

3. Maria is a utility-maximiser and she has an income of £50 to allocate between cherries (good 1) and peaches (good 2). The price of cherries is £5, while the price of peaches is £4. Her

marginal rate of substitution (i.e. the rate at which Maria is willing to give up peaches in exchange for cherries) is: $MRS(q_C, q_P) = \frac{2q_P}{q_C}$. Here, q_C and q_p are the quantities of cherries and peaches, respectively.

(i) Calculate the optimal quantity of cherries and peaches and show the solution in a diagram. (20 marks)

(ii) Now suppose that the price of cherries increases to £12. Calculate the impact of the increase in the price of cherries on Maria's optimal demand for the two goods; show the effect in a diagram and comment. (15 marks)

(iii) Show how the total change in the optimal quantities you found in (ii) can be decomposed into a substitution and an income effect. (15 marks)

Kurt has the same income as Maria and observes the same prices in the market. However, his utility function is: $U(q_C, q_P) = 4q_C + 2q_P$.

(iv) Calculate the optimal quantity of cherries and peaches for Kurt; show the solution in a diagram and comment. (20 marks)

(v) Consider the same price increase as in question (ii). Show the impact of the change in the price of cherries on Kurt's demand for the two goods using a diagram. (15 marks)

(vi) Decompose the total change in the optimal quantities you found in (v) into the substitution and the income effect. (15 marks)

4. Consider a firm using capital and labour in the production process. The production function of the firm is $q = A\, min\{10K, 2L\}$, where A is the overall productivity of the firm. Assume that $A = 2$.

(i) Calculate the optimal quantity of capital and labour; show the solution in a diagram and comment. (20 marks)

(ii) Derive the total cost function of the firm, draw it and comment on its shape. (10 marks)

(iii) Suppose that the level of technology of the firm A decreases to 1. Calculate the impact on the total costs of the firm; provide an explanation and a graph. (10 marks)

(iv) Consider a market characterized by natural monopoly. Explain what natural monopoly means using a graph. Should the government regulate the market? If so, what do you suggest and why? Explain carefully using diagrams. (30 marks)

(v) Consider two firms competing à la Cournot. The market demand curve is: $p = 10 - Q$, where $Q = q_1 + q_2$. The total cost function is identical for the two firms: $TC_1(q) = TC_2(q) = q$. Calculate the economic profit of the two firms and illustrate the result in a graph. (20 marks)

(vi) Suppose that the two firms now compete à la Bertrand. What is the economic profit of the two firms? (10 marks)

SECTION C
Answer one question.

5. Suppose that a country has the following aggregate production function: $Y = F(K, L) = 6 \cdot K^{1/3}L^{2/3}$, where *K* is the amount of capital and *L* is the amount of labour hours. Answer the following questions.

(i) What is the per-person production function, *y = f(k)*, in this country? Here, *k* is defined as *K*/*L*. (10 marks)

(ii) What is the equation of motion for *k* if the saving rate is *s* and the depreciation rate of capital is δ? Explain each term of the equation, why you have it and how the steady state is achieved by using a graph. (10 marks)

(iii) Calculate the steady-state per-person capital stock, *k**, assuming that the depreciation rate is 5 percent and the saving rate is also 5 percent. How does the steady-state capital stock change if both the depreciation rate and saving rate double in the economy? (15 marks)

(iv) Suppose that the depreciation rate is 5 percent. Which level of saving rate leads to the Golden-rule steady state capital stock? Explain. Hint: $dx^{\rho}/dx = \rho x^{\rho-1}$. (25 marks)

(v) Suppose that the country has instead the following production function: $F(K, L) = K + 3L$. What is the steady-state level of capital and consumption per person? Assume that the depreciation rate and the saving rate are both 5 percent. (20 marks)

(vi) Suppose that the country has instead the following production function: $F(K, L) = K - 3L$? What is the steady-state level of capital and consumption per person? Assume that the depreciation rate and the saving rate are both 5 percent. (20 marks)

6. Answer each of the following questions.

(i) Derive the government expenditure multiplier in the very short run under a closed economy. (10 marks)

(ii) Explain mathematically how the government expenditure multiplier you found in (i) changes if the country becomes an open economy. (10 marks)

(iii) Explain mathematically which multiplier is bigger, the government expenditure or the tax multiplier, and interpret the comparison. (10 marks)

(iv) Suppose that the economy operates as a closed economy. The IS-LM model is used to study how GDP changes when interest rates are flexible. Using appropriate diagram (s), carefully explain how the IS curve is derived. (20 marks)

(v) Suppose that the economy operates as a closed economy and that it is at full-employment equilibrium. Suppose also that taxes in this economy are decreased. Assume that the objective of the central bank is to keep the interest rate constant. Explain carefully which monetary policy is required to achieve this objective following the change in fiscal policy and its short-run impact on real GDP using the IS-LM model and money market model. (25 marks)

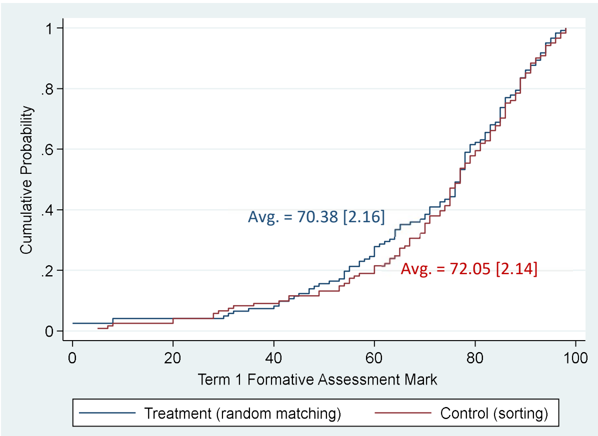
(vi) As in question (iii), suppose that the economy operates as a closed economy, and it is at full-employment equilibrium. Suppose also that the government decreases income taxes in the economy. Explain the effects of the tax cut on long-run macro equilibrium by drawing appropriate graphs. (25 marks)

Section B: Additional Figures and Tables

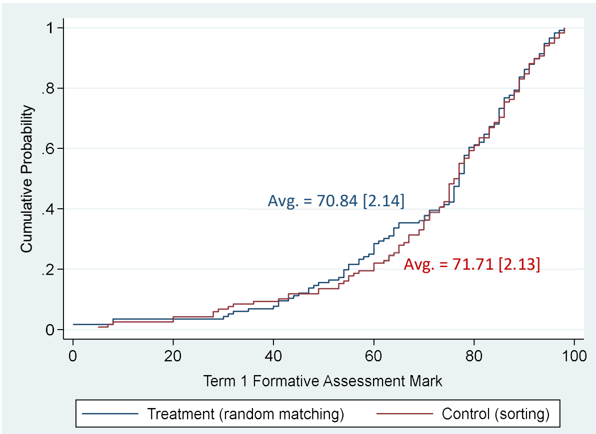
Figure B.1: *Distribution of Students' Term 1 Formative Assessment Marks*

The only assessment marked by academic staff in term 1 is the formative assessment. Students' marks for the assessment can be thought of as their performance in the middle of term 1 in the module. As explained, an intervention in term 2 was made according to students' term 1 formative assessment marks. Hence, it is important to check how the marks are balanced between the treatment and the control conditions as a randomization check.

As already discussed in the paper, the summary statistics show that students' term 1 formative performances were insignificantly larger in the control than in the treatment condition (Table 1 of the paper). Thus, the marks are statistically balanced. To supplement the analysis, the followings report the cumulative distributions of students' term 1 formative assessment marks by the condition.



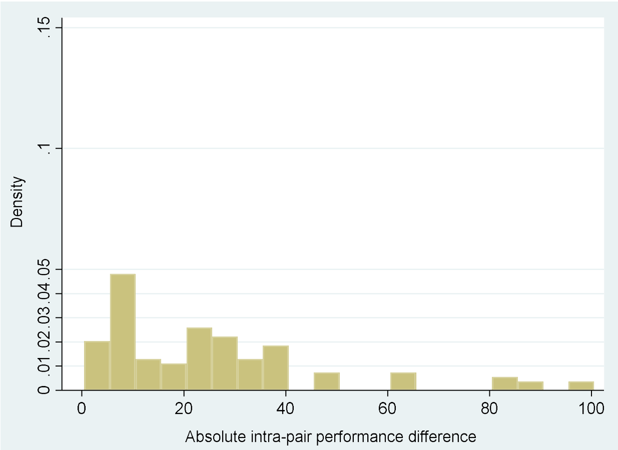
(A) All students in the subject pool



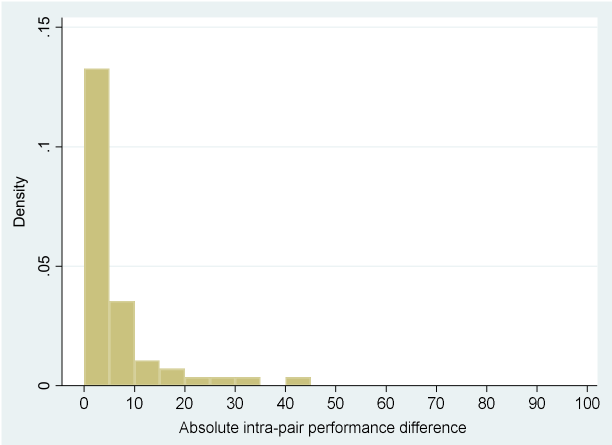
(B) Students who completed summative assessments

Notes: The numbers in squared brackets are standard errors clustered by seminar ID.

Figure B.2: *Students' Term 1 Formative Assessment Marks by Relative Performance Standing within Pairs in the Treatment condition*

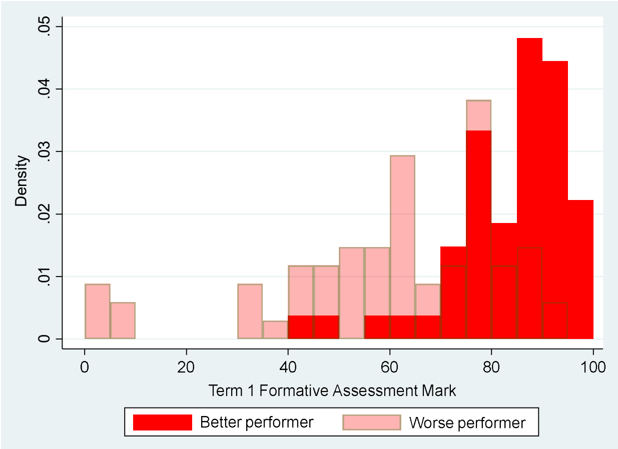


A1. The treatment condition (random matching)



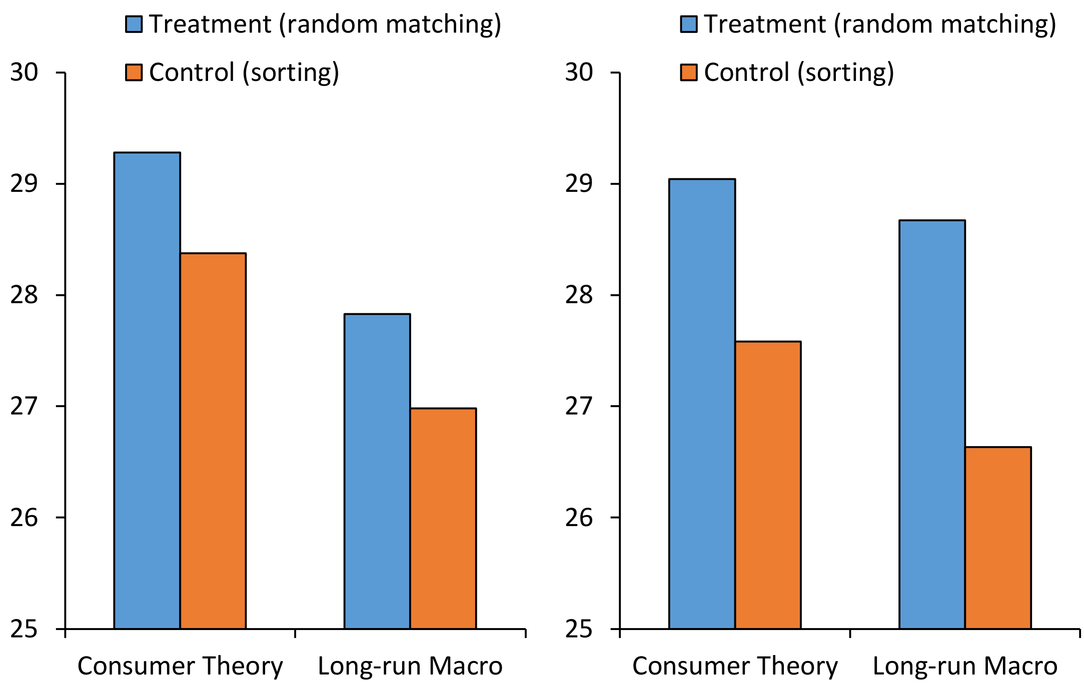
A2. The control condition (sorting)

(A) Histogram of absolute intra-pair performance difference in terms of term 1 formatives



(B) Histogram by relative performance standing in the treatment condition

Figure B.3: *Students' Average Marks in the PRA topics in the Summative Assessment (supplementing Panels B and C of Figure 5 in the paper)*



(a) Better performers (b) Worse performers

Table B.1: *Treatment Effects of Term 2 Random Matching (supplementing Table 2 of the paper)*

(A) Second Stage Regression (Treatment effect)

Dependent variable: Summative assessment mark of student *i*

Data:	(I) All data		(II) Both *i* and *i*'s partner submitted term 2 PRAs	
Independent variable:	(i)	(ii)	(i)	(ii)
(a) t2 random matching dummy {=1(0) for the treatment (control) condition}	3.17*** (1.10)	2.75*** (1.07)	2.57** (1.22)	2.37** (1.21)
(b) A dummy that equals 1 if *i* did not submit term 1 formative assessment	---	6.16 (5.81)	---	6.74 (6.83)
(c) Interaction term: (1 – variable (b)) × term 1 formative assessment mark	---	0.17*** (0.046)	---	0.16*** (0.059)
(d) Female dummy {=1 for female student; = 0 otherwise}	0.98 (1.67)	1.15 (1.72)	0.32 (1.53)	0.69 (1.53)
(e) Female partner dummy {1 if partner is female; = 0 otherwise}	-2.47 (2.18)	-1.73 (2.34)	-2.29 (2.14)	-1.66 (2.26)
(f) Interaction: variable (d) × variable (e)	3.25 (2.46)	2.51 (2.48)	3.61 (2.46)	2.64 (2.66)
(g) British dummy {=1(0) for British (Non-British) student}	-0.69 (1.96)	1.33 (2.27)	0.16 (1.37)	1.35 (1.69)
A three-student team dummy {= 1(0) if a student was assigned to a three(two)-student team}	-6.03* (3.47	0.31 (3.59)	-4.25 (4.07)	0.77 (4.19)
Constant	70.29*** (2.06)	57.53*** (3.29)	70.13*** (1.86)	58.36*** (4.16)
# observations	259	259	236	236
# selected	250	250	228	228
Log pseudolikelihood	-999.96	-1000.41	-903.76	-890.17

(B) Selection equation that explains whether student *i* submits the summative assessment (i.e., the submission is observed)

Data:	(I) All data		(II) Both *i* and *i*'s partner submitted term 2 PRAs	
Independent variable:	(i)	(ii)	(i)	(ii)
(a) t2 random matching dummy {=1(0) for the treatment (control) condition}	-0.29 (0.64)	-0.40 (0.32)	-0.28 (0.32)	0.001 (0.10)
(b) A dummy that equals 1 if *i* did not submit term 1 formative assessment	---	5.44*** (0.72)	---	0.61 (n.a)
(c) Interaction term: (1 – variable (b)) × term 1 formative assessment mark	---	0.004 (0.008)	---	-0.000 (0.01)
(d) Female dummy {=1 for female student; = 0 otherwise}	0.93 (0.19)	-0.09 (0.60)	-0.06 (0.48)	-0.90*** (0.13)
(e) Female partner dummy {1 if partner is female; = 0 otherwise}	0.62 (0.48)	-0.003 (0.55)	0.07 (0.48)	-0.31 (0.20)
(f) Interaction: variable (d) × variable (e)	-1.36 (1.00)	0.10 (0.87)	-0.01 (0.68)	0.74*** (0.24)
(g) British dummy {=1(0) for British (Non-British) student}	0.49 (0.62)	0.68 (0.57)	0.71 (0.59)	0.10 (0.15)
(h) The number of formative assessments not submitted {= 0, 1, 2}	-0.27 (0.45)	-0.54** (0.24)	-0.70*** (0.27)	-1.24*** (0.06)
(i) Seminar attendance rate ∈ [0, 1]	-0.48	0.45	0.72	0.88***

	(20.55)	(0.72)	(0.72)	(0.04)
A three-student team dummy {= 1(0) if a student was assigned to a three(two)-student team}	0.39	4.63***	4.58***	1.24
	(0.45)	(0.91)	(0.66)	(n.a.)
Constant	1.74*	1.57**	1.76***	2.28***
	(1.00)	(0.62)	(0.66)	(0.38)

Notes: Estimations of the Heckman two-stage selection model with robust standard errors clustered by seminar group ID. The numbers in parentheses are standard errors. In addition to the independent variables listed in the table, a term 1 tutor dummy was controlled in both stages of regressions since there were two seminar tutors in term 1. A three-student team dummy was also added as a control since there was one such team in a session whose number of students was odd. The female partner dummy is defined as 0 (both of the other two are male), 0.5 (one of the other two is female) or 1 (both of the other two are female) for the case of a three-student team. In column IIs, only observations in which a student submitted term 2 peer review assessment and their partner also submitted it were used as data. Equations I.i, I.ii, II.i, and II.ii of panel B are the selection equations of columns I.i, I.ii, II.i, and II.ii, respectively, of panel A.

*, **, and *** indicate significance at the 0.10 level, at the 0.05 level and at the 0.01 level, respectively.

Table B.2: *Mechanism behind the Positive Impact of Term 2 Random Matching (supplementing Table 3 of the paper)*

(A) Second Stage Regression

Dependent variable: Summative assessment mark of student *i*

Data:	(I) All data		(II) Both *i* and *i*'s partner submitted term 2 PRAs	
Independent variable:	(i)	(ii)	(i)	(ii)
(a) Better performer dummy: $\mathbf{1}\{x_i > x_{j,\text{ random matching}}\}$ #1	1.86**	0.21	2.18*	-0.017
	(0.89)	(1.11)	(1.25)	(1.43)
(b) Worse performer dummy: $\mathbf{1}\{x_i < x_{j,\text{ random matching}}\}$ #2	3.11**	5.52***	1.28	3.87**
	(1.54)	(1.64)	(2.31)	(1.81)
(c) Term 1 formative assessment mark (x_i)	---	0.19***	---	0.20***
		(0.048)		(0.063)
(d) Female dummy {=1 for female student; = 0 otherwise}	1.55	2.02	1.05	1.27
	(1.89)	(1.82)	(1.57)	(1.41)
(e) Female partner dummy {1 if partner is female; = 0 otherwise}	-1.43	-1.04	-1.39	-1.03
	(2.20)	(2.45)	(2.19)	(2.39)
(f) Interaction: variable (d) × variable (e)	2.03	1.28	2.65	1.96
	(2.15)	(2.42)	(2.64)	(2.61)
(g) British dummy {=1(0) for British (Non-British) student}	-1.12	-0.26	0.56	1.29
	(1.65)	(1.99)	(1.35)	(1.77)
A three-student team dummy {= 1(0) if a student was assigned to a three(two)-student team}	-6.41	1.04	-3.88	1.42
	(4.66)	(4.00)	(5.43)	(4.48)
Constant	70.74***	56.87***	69.98***	55.96***
	(1.73)	(3.60)	(1.78)	(4.22)
# observations	243	243	226	226
# selected	234	234	218	218
Log pseudolikelihood	-932.19	-923.49	-860.63	-851.31

(B) Selection equation that explains whether student *i* submits the summative assessment (i.e., the submission is observed)

Data:	(I) All data		(II) Both *i* and *i*'s partner submitted term 2 PRAs	
Independent variable:	(i)	(ii)	(i)	(ii)
(a) Better performer dummy: $\mathbf{1}\{x_i > x_{j,\text{ random matching}}\}$ #1	-0.32***	-0.33**	-0.24	-0.15
	(0.081)	(0.13)	(0.88)	(0.12)
(b) Worse performer dummy: $\mathbf{1}\{x_i < x_{j,\text{ random matching}}\}$ #2	0.19	-0.13	0.58	-0.23
	(0.12)	(0.15)	(1.78)	(0.16)
(c) Term 1 formative assessment mark (x_i)	---	-0.008	---	-0.003
		(0.006)		(0.006)
(d) Female dummy {=1 for female student; = 0 otherwise}	0.39**	0.39**	-0.36	-1.11
	(0.16)	(0.18)	(0.54)	(0.13)
(e) Female partner dummy {1 if partner is female; = 0 otherwise}	0.22	0.43**	0.004	-0.43**
	(0.18)	(0.21)	(0.65)	(0.21)
(f) Interaction: variable (d) × variable (e)	-0.47**	-0.71***	-0.06	1.10***
	(0.19)	(0.23)	(1.14)	(0.25)
(g) British dummy {=1(0) for British (Non-British) student}	0.67***	0.50***	-0.12	0.37**
	(0.14)	(0.18)	(2.42)	(0.15)
(h) The number of formative assessments not submitted {= 0, 1, 2}	-0.55***	-0.62***	-1.07	-1.30***
	(0.034)	(0.11)	(0.80)	(0.07)
(i) Seminar attendance rate ∈ [0, 1]	0.35***	0.62***	0.80	1.13***
	(0.021)	(0.03)	(2.18)	(0.06)

A three-student team dummy {= 1(0) if a student was assigned to a three(two)-student team}	2.76 (n.a.)	n.a.[#3]	0.74 (2.67)	1.17*** (0.39)
Constant	1.34*** (0.18)	1.86*** (0.52)	2.15 (1.69)	2.37*** (0.41)

Notes: Estimations of the Heckman two-stage selection model with robust standard errors clustered by seminar group ID. The numbers in parentheses are standard errors. In addition to the independent variables listed in the table, a term 1 tutor dummy was controlled in both stages of regressions since there were two seminar tutors in term 1. Only observations in which a student submitted term 1 formative and their partner also submitted it were used as data. A three-student team dummy was also added as a control since there was one such team in a session whose number of students was odd. The female partner dummy is defined as 0 (both of the other two are male), 0.5 (one of the other two is female) or 1 (both of the other two are female) for the case of a three-student team. [#1] **1**{$x_i > x_j$, random matching} is an indicator variable which equals 1 if $x_i > x_j$ and i is in the treatment condition; 0 otherwise. Here, x_i (x_j) is i's (i's partner j's) term 1 formative assessment mark [#2] **1**{$x_i < x_j$, random matching} is an indicator variable which equals 1 if $x_i < x_j$, and i is in the treatment condition; 0 otherwise. The reference group is observations in the Sorting condition. Equations I.i, I.ii, II.i, and II.ii of panel B are the selection equations of columns I.i, I.ii, II.i, and II.ii, respectively, of panel A. [#3] The three-student team dummy was not included in the section equation here since otherwise the model was not converged.

*, **, and *** indicate significance at the 0.10 level, at the 0.05 level and at the 0.01 level, respectively.

Table B.3: *The Impact of Term 2 Random Matching by Part in the Summative Assessment (supplementing Table 4 of the paper)*

The following table shows the estimation result when all data are used. As were estimated for Tables 2 and 3 of the paper, the same model was estimated also using the subset of data where both *i* and *i*'s partner submitted the term 2 PRA, generating qualitatively the same results. The results are omitted to conserve space.

(A) Second Stage Regression

Dependent variable:	(I) Mark of student *i* in Q3 (Consumer Theory)				(II) Mark of student *i* in Q5 (Long-run Macro)			
Independent variable:	(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
(a) t2 random matching dummy {=1(0) for the treatment (control) condition}	1.37** (0.66)	1.43** (0.65)	---	---	1.51** (0.46)	1.81*** (0.49)	---	---
(b) A dummy that equals 1 if *i* did not submit term 1 formative assessment	---	4.92** (2.35)	---	---	---	-2.27 (3.51)	---	---
(c) Interaction term: (1 – (b)) × term 1 formative assessment mark	---	0.08*** (0.025)	---	---	---	0.02 (0.03)	---	---
(d) Better performer dummy: $\mathbf{1}\{x_i > x_j$, random matching$\}$[#1]	---	---	0.93* (0.49)	0.05 (0.52)	---	---	0.27 (0.53)	-0.25 (0.52)
(e) Worse performer dummy: $\mathbf{1}\{x_i < x_j$, random matching$\}$[#2]	---	---	1.66 (1.09)	3.04*** (0.99)	---	---	1.30* (0.69)	1.95** (0.78)
(f) Term 1 formative assessment mark (x_i)	---	---	---	0.10*** (0.03)	---	---	---	0.052** (0.02)
A three-student team dummy {= 1(0) if a student was assigned to a three(two)-student team}	-0.63 (2.09)	n.a.[#4]	-1.16 (2.52)	1.73 (2.12)	-4.17*** (1.16)	n.a.[#4]	-3.80 (2.55)	-2.30 (2.46)
Constant	29.40*** (0.57)	24.4*** (1.79)	29.35*** (0.49)	22.43*** (1.84)	27.20*** (0.48)	26.36*** (2.30)	27.73*** (0.58)	24.18*** (1.79)
# observations	259	259	243	243	259	259	243	243
# selected	245	245	230	230	229	229	215	215
Log pseudolikelihood	-867.57	-862.34	-813.24	-806.64	-815.58	-794.90	-753.79	-749.77

(B) Selection equation that explains whether student *i* submits the summative assessment (i.e., the submission is observed)[#3]

Dependent variable:	(I) Mark of student *i* in Q3 (Consumer Theory)				(II) Mark of student *i* in Q5 (Long-run Macro)			
Independent variable:	(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
(a) r2 random matching dummy {=1(0) for the treatment (control) condition}	-0.18** (0.09)	-0.12 (0.09)	---	---	-0.12 (0.13)	0.07 (0.07)	---	---

(b) A dummy that equals 1 if i did not submit term 1 formative assessment	---	-0.40 (0.31)	---	---	---	-0.10 (0.52)	---	---
(c) Interaction term: (1 – (b)) × term 1 formative assessment mark	---	-0.003 (0.003)	---	---	---	-0.004 (0.005)	---	---
(d) Better performer dummy: **1**{$x_i > x_j$, random matching}[#1]	---	---	-0.10 (0.06)	-0.02 (0.07)	---	---	-0.20 (0.23)	-0.26 (0.24)
(e) Worse performer dummy: **1**{$x_i < x_j$, random matching}[#2]	---	---	-0.22 (0.15)	-0.33** (0.14)	---	---	-0.05 (0.27)	0.09 (0.22)
(f) Term 1 formative assessment mark (x_i)	---	---	---	-0.006* (0.003)	---	---	---	0.008 (0.005)
(g) The number of formative assessments not submitted {= 0, 1, 2}	0.00 (0.00)	-0.10*** (0.004)	0.05*** (0.002)	-0.17*** (0.007)	-0.01 (0.20)	-0.18*** (0.01)	-0.037 (0.24)	-0.06 (0.25)
(h) Seminar attendance rate ∈ [0, 1]	0.00 (0.00)	-0.05*** (0.002)	0.21*** (0.009)	0.08*** (0.003)	-0.25 (0.63)	-0.12*** (0.01)	-0.31 (0.67)	-0.48 (0.68)
A three-student team dummy {= 1(0) if a student was assigned to a three(two)-student team}	0.08 (0.27)	n.a.	4.09 (n.a.)	3.92 (n.a.)	-0.03 (0.40)	n.a.	-0.26 (0.38)	-0.019 (0.42)
Constant	1.36*** (0.07)	1.70*** (0.24)	1.19*** (0.06)	1.94*** (0.26)	1.58*** (0.54)	1.50*** (0.35)	1.74*** (0.57)	1.32* (0.69)

Notes: Estimations of the Heckman two-stage selection model with robust standard errors clustered by seminar group ID. The numbers in parentheses are standard errors. All data where students completed the summative assessment and gave consent for the inclusion in data analysis are used. In addition to the independent variables listed in the table, a term 1 tutor dummy was controlled in both stages of regressions since there were two seminar tutors in term 1. A three-student team dummy was also added as a control since there was one such team in a session whose number of students was odd. For columns I.iii, I.iv, II.iii, and II.iv, only observations in which a student submitted term 1 formative and their partner also submitted it were used as data.

[#1] **1**{$x_i > x_j$, random matching} is an indicator variable which equals 1 if $x_i > x_j$ and i is in the treatment condition; 0 otherwise. Here, x_i (x_j) is i's (i's partner j's) term 1 formative assessment mark

[#2] **1**{$x_i < x_j$, random matching} is an indicator variable which equals 1 if $x_i < x_j$ and i is in the treatment condition; 0 otherwise.

[#3] Equations I.i, I.ii, I.iii, I.iv, II.i, II.ii, II.iii and II.iv of panel B are the selection equations of columns I.i, I.ii, I.iii, I.iv, II.i, II.ii, II.iii and II.iv, respectively, of panel A. Unselected students mean those who did not submit the summative assessment or those who answered Q4 in Part B (Q6 in Part C) although they completed the assessment.

[#4] The three-team dummy was removed because otherwise convergence was not reached.

*, **, and *** indicate significance at the 0.10 level, at the 0.05 level and at the 0.01 level, respectively.

Table B.4: *Mechanism behind the Positive Impact of Term 2 Random Matching (supplementing Tables 3 and 4 of the paper and Appendix Tables B.2 and B.3)*

The analysis in Tables 3 and 4 of the paper divided students into two sets: the "better performers" and the "worse performers," according to whether a student's term 1 formative mark was better (worse) than their matched partner's. However, another way to classify students is based on an absolute perspective regarding whether a student's term 1 formative mark was above the median mark in the module or not. This alternative approach enables us to study how different pairings affected performance. To supplement the earlier analysis, the following four variables are defined:

Better: a dummy which equals 1(0) if a student's performance in the term 1 formative was above the median performance in the module

Worse: 1 – Better, i.e., a dummy which equals 1(0) if a student's performance in the term 1 formative was not above the median performance in the module

pBetter: a dummy which equals 1(0) if a student's term 2 PRA partner's performance in the term 1 formative was above the median performance in the module

pWorse: 1 – pBetter, i.e., a dummy which equals 1(0) if a student's term 2 PRA partner's performance in the term 1 formative was not above the median performance in the module

Here, the median mark of the term 1 formative was 76. Because the number of students whose mark was exactly the median is only nine and it is therefore not meaningful to set another category where the mark is exactly equal to the median, we simply classify subjects regarding whether their interim mark was above median or not, i.e., an "above-median" performer or a "below-median" performer (which also includes those at the median).

In the additional regression, three interaction variables: Better × pWorse, Worse × pBetter, Worse × pWorse are used while the case of Better × pBetter is the reference group. The results summarized below are consistent with the message found from Table 3 and 4 as follows:

(a) the "above-median" performers were not harmed when matched with a "below-median" performer.

(b) the "below-median" performers benefited from being matched with an "above-median" performer.

[Regression Result:]

(A) Second Stage Regression

Dependent variable: Summative assessment mark of student *i*

Dependent variable:	Overall mark		Part B mark		Part C mark	
Independent variable:	(i)	(ii)	(i)	(ii)	(i)	(ii)
(a) Better × pWorse	0.36 (1.51)	0.35 (1.70)	0.31 (1.24)	0.47 (1.32)	-0.05 (0.53)	-0.006 (0.63)
(b) Worse × pBetter	5.69*** (2.54)	5.81** (2.51)	3.92*** (1.47)	3.68*** (1.41)	1.90 (1.23)	1.99 (1.32)
(c) Worse × pWorse	2.93 (1.91)	2.87 (2.02)	0.87 (1.35)	1.45 (1.35)	-0.43 (1.18)	-0.50 (1.33)
(d) Term 1 formative assessment mark (x_i)	0.22*** (0.05)	0.22*** (0.05)	0.11*** (0.03)	0.12*** (0.03)	0.047* (0.028)	0.04 (0.03)
(e) Female dummy {=1 for female student; = 0 otherwise}	---	1.96 (1.71)	---	0.56 (1.14)	---	0.65 (0.85)
(f) Female partner dummy {1 if partner is female; = 0 otherwise}	---	-0.72 (2.61)	---	0.12 (1.27)	---	-0.31 (1.46)

(g) Interaction: variable (e) × variable (f)	---	0.96 (2.42)	---	0.24 (1.66)	---	0.57 (1.52)
(h) British dummy {=1(0) for British (Non-British) student}	---	0.95 (1.80)	---	2.19 (1.34)	---	-1.99 (0.94)
A three-student team dummy {= 1(0) if a student was assigned to a three(two)-student team}	-0.04 (3.70)	0.41 (3.66)	2.04 (2.19)	3.16 (2.11)	-2.28 (2.04)	-1.77 (2.12)
Constant	54.10*** (4.55)	52.88*** (4.79)	21.23*** (2.37)	18.33*** (2.67)	24.85*** (2.52)	25.46*** (3.29)
# observations	243	243	243	243	243	243
# selected	234	234	234	234	234	234
Log pseudolikelihood	-936.77	-934.61	-806.48	-816.44	-761.82	-756.73

(B) Selection equation that explains whether student i submits the summative assessment (i.e., the submission is observed)

Data:	(I) All data		Part B mark		Part C mark	
Independent variable:	(i)	(ii)	(i)	(ii)	(i)	(ii)
(a) Better × pWorse	0.07 (0.52)	0.10 (0.47)	-0.24 (0.17)	0.10 (0.48)	-0.52*** (0.10)	-0.29 (0.70)
(b) Worse × pBetter	-0.15 (0.36)	-0.21 (0.36)	-0.24 (1.17)	-0.20 (0.44)	0.45** (0.20)	0.16 (0.43)
(c) Worse × pWorse	0.49 (0.61)	0.39 (0.50)	-0.052 (1.19)	0.40 (0.49)	0.21 (0.20)	0.47 (0.91)
(d) Term 1 formative assessment mark (x_i)	0.006 (0.009)	0.006 (0.008)	0.002 (0.004)	0.005 (0.008)	0.005 (0.005)	-0.002 (0.007)
(e) Female dummy {=1 for female student; = 0 otherwise}	---	-0.06 (0.52)	---	-0.01 (0.52)	---	-0.059 (0.78)
(f) Female partner dummy {1 if partner is female; = 0 otherwise}	---	0.02 (0.44)	---	0.038 (0.49)	---	-0.31 (0.52)
(g) Interaction: variable (e) × variable (f)	---	0.10 (0.71)	---	0.062 (0.81)	---	-0.009 (0.73)
(h) British dummy {=1(0) for British (Non-British) student}	---	0.60 (0.59)	---	0.63 (0.83)	---	0.23 (0.66)
(i) The number of formative assessments not submitted {= 0, 1, 2}	-0.48* (0.26)	-0.48** (0.24)	-0.45*** (0.02)	-0.45* (0.26)	-0.67*** (0.042)	-0.65 (0.43)
(j) Seminar attendance rate ∈ [0, 1]	0.02 (0.69)	0.27 (0.73)	-0.07 (0.003)	0.21 (0.92)	0.67*** (0.04)	0.17 (0.48)
A three-student team dummy {= 1(0) if a student was assigned to a three(two)-student team}	5.48*** (0.34)	6.74*** (0.39)	1.77 (n.a.)	4.97*** (0.72)	9.05 (n.a.)	n.a.[#1]
Constant	1.52** (0.73)	1.23 (0.86)	1.79 (1.27)	1.26 (1.08)	0.55 (0.42)	1.42** (0.58)

Notes: Estimations of the Heckman two-stage selection model with robust standard errors clustered by seminar group ID. The numbers in parentheses are standard errors. In addition to the independent variables listed in the table, a term 1 tutor dummy was controlled in both stages of regressions since there were two seminar tutors in term 1. Only observations in which a student submitted term 1 formative and their partner also submitted it were used as data. A three-student team dummy was also added as a control since there was one such team in a session whose number of students was odd. The female partner dummy is defined as 0 (both of the other two are male), 0.5 (one of the other two is female) or 1 (both of the other two are female) for the case of a three-student team. [#1] The three-student team dummy was not included in the section equation here since otherwise the model was not converged.

*, **, and *** indicate significance at the 0.10 level, at the 0.05 level and at the 0.01 level, respectively.

Section C: Theoretical Analysis

Either social effects, such as shame and pride (Section C.1), or interdependent motives (Section C.2), predict that (i) students perform better on the summative assessment in pairs with a greater spread in interim performances than in those with similar interim performances, and (ii) especially the worse performers in the treatment condition improve performances through working with their matched better performers, in the setup of this study. This Appendix mathematically illustrates the mechanism of each motive in isolation by either assuming $x_i = 0$ (Section C.1) or $\mu_i = 0$ (Section C.2) in Equations (6) and (7) of the paper.

The analysis below uses the following payoff functional forms, rather than Equations (4) and (5) of the paper:

$$\pi_h(y_h, e_h|e_l) = G_h(y_h) + a_l e_l + b_h e_h - c_h {e_h}^2. \tag{C1}$$

$$\pi_l(y_l, e_l|e_h) = G_l(y_l) + a_h e_h + b_l e_l - c_l {e_l}^2. \tag{C2}$$

The difference from Equation (4) or (5) is only the presence of $b_i e_i$ in each equation. The term $b_i e_i$ refers to student *i*'s own benefit from engaging in the PRA activities. In Section 4 of the paper, b_i is set at 0 for simplicity. With this amendment, we have the following utility functional forms:

$$\theta_h(y_h, e_h|e_l) = \pi_h(y_h, e_h|e_l) + \mu_h[\{g(y_h) + a_l e_l + b_h e_h\} - \{g(y_l) + a_h e_h + b_l e_l\}]^2 - x_h \cdot (\pi_h - \pi_l)^2. \tag{C3}$$

$$\theta_l(y_l, e_l|e_h) = \pi_l(y_l, e_l|e_h) - \mu_l[\{g(y_h) + a_l e_l + b_h e_h\} - \{g(y_l) + a_h e_h + b_l e_l\}]^2 - x_l \cdot (\pi_h - \pi_l)^2. \tag{C4}$$

C.1. Social Effects among Peer Mates

To isolate the impact of social effects, Section C.1 assumes that $x_i = 0$.

$$\theta_h(y_h, e_h|e_l) = \pi_h(y_h, e_h|e_l) + \mu_h[\{g(y_h) + a_l e_l + b_h e_h\} - \{g(y_l) + a_h e_h + b_l e_l\}]^2. \tag{C5}$$

$$\theta_l(y_l, e_l|e_h) = \pi_l(y_l, e_l|e_h) - \mu_l[\{g(y_h) + a_l e_l + b_h e_h\} - \{g(y_l) + a_h e_h + b_l e_l\}]^2. \tag{C6}$$

First, Equations (C1) and (C2) suggest that unless the social effects are taken into account, the PRA activities do not increase each type's optimal effort choice decision regarding y_i, because $\frac{\partial \pi_i(y_i, e_i|e_j)}{\partial y_i} = \frac{\partial G_i(y_i)}{\partial y_i}$ for *i* = *h*, *l*. However, the presence of social effects ($\mu > 0$)

influences their self-study effort in the PRA activities. This can be seen by using the first-order conditions for Equations (C5) and (C6) as follows:

$$\frac{\partial\theta_h}{\partial y_h} = \beta_h - 2\gamma_h y_h + 2\mu_h\beta_h[\{g(y_h) + a_l e_l + b_h e_h\} - \{g(y_l) + a_h e_h + b_l e_l\}] = 0. \quad \text{(C7)}$$

$$\frac{\partial\theta_l}{\partial y_l} = \beta_l - 2\gamma_l y_l + 2\mu_l\beta_l[\{g(y_h) + a_l e_l + b_h e_h\} - \{g(y_l) + a_h e_h + b_l e_l\}] = 0. \quad \text{(C8)}$$

Notice that

$$\frac{\partial\theta_h}{\partial y_h}\Big|_{y_h^*=\frac{\beta_h}{2\gamma_h}, y_l^*=\frac{\beta_l}{2\gamma_l}} = 2\mu_h\beta_h\left[\alpha_h - \alpha_l + \frac{\beta_h^{\,2}}{2\gamma_h} - \frac{\beta_l^{\,2}}{2\gamma_l} + a_l e_l + b_h e_h - a_h e_h - b_l e_l\right].$$

$$\frac{\partial\theta_l}{\partial y_l}\Big|_{y_h^*=\frac{\beta_h}{2\gamma_h}, y_l^*=\frac{\beta_l}{2\gamma_l}} = 2\mu_l\beta_l\left[\alpha_h - \alpha_l + \frac{\beta_h^{\,2}}{2\gamma_h} - \frac{\beta_l^{\,2}}{2\gamma_l} + a_l e_l + b_h e_h - a_h e_h - b_l e_l\right].$$

Here, the squared bracket (the difference in achievement level between the high and low types after the PRA activities) is considered as still positive because $\alpha_h > \alpha_l$, $\frac{\beta_h^{\,2}}{2\gamma_h} > \frac{\beta_l^{\,2}}{2\gamma_l}$ and $0 < \mu_h < \mu_l$. This suggests that the optimal self-study effort exerted by type *i* after the PRA activities (denoted as y_i^{**}) is greater than $y_i^* = \frac{\beta_i}{2\gamma_i}$. In other words, both the high and low types work harder and therefore achieve higher academic performance driven by the social effects. Conditions (C7) and (C8) can also be simplified to:

$$\frac{y_h - \frac{\beta_h}{2\gamma_h}}{y_l - \frac{\beta_l}{2\gamma_l}} = \frac{\frac{\mu_h\beta_h}{\gamma_h}}{\frac{\mu_l\beta_l}{\gamma_l}} = \frac{\mu_h}{\mu_l}\frac{\gamma_l\beta_h}{\gamma_h\beta_l}.$$

By the assumptions on β and γ, $\frac{\gamma_l\beta_h}{\gamma_h\beta_l} > 1$. Thus, the above condition implies that the low type shows a stronger improvement than the high type if the effect of shame is large enough that $\mu_l > \frac{\gamma_l\beta_h}{\gamma_h\beta_l}\mu_h$.

These analytical implications can be summarized as Proposition 1 below. Proposition 1 suggests that peer review activities with a greater spread in interim performances lead to a stronger effect on academic performance than those with similar performances, as the social effects operate strongly in the former than in the latter.

Proposition 1: *Suppose that the high (low) type receives a positive (negative) utility due to feelings of pride (shame) through the PRA activities. Then, the PRA activities encourage both the high and low types to improve their academic performance. The positive effect on the low type is stronger than that on the high type if the low type is concerned about shame large enough that* $\mu_l > \frac{\gamma_l\beta_h}{\gamma_h\beta_l}\mu_h$.

C.2. Interdependent Motives

The mutual learning hypothesis states that high-ability workers teach less-ability ones, thereby improving the performances of especially the latter. To see this, for tractability, let us simplify the payoff functions (C1) and (C2) as follows:

$$\pi_h(e_h|e_l) = k_h + a_l e_l + b_h e_h - c_h {e_h}^2. \quad \text{(C9)}$$

$$\pi_l(e_l|e_h) = k_l + a_h e_h + b_l e_l - c_l {e_l}^2. \quad \text{(C10)}$$

Here, k_h and k_l are *G*-values before engaging in the PRA activities, i.e., $k_i = G_i({y_i}^*)$, where ${y_i}^* = \frac{\beta_i}{2\gamma_i}$. As discussed in Section 4 of the paper, $k_h > k_l > 0$, and, for simplicity, assume that these are constants through the PRA activities. This is a reasonable assumption because $y_h \geq {y_h}^*$ and $y_l \geq {y_l}^*$ (the students cannot reverse effort they have already put prior to the PRA). What each type can do in the PRA activities is whether to put additional self-study effort beyond ${y_i}^*$. Recall that putting additional self-study effort reduces their utility levels (also see Equations (C13) and (C14) below). Thus, unlike the assumption of the social effects, the interdependent motives do not cause the low type to put additional effort beyond ${y_i}^*$.

In this framework, when the interdependent motives are not considered, each type's optimal effort provision to teach the partner can be derived by using the first-order conditions for (C9) and (C10):

$${e_h}^* = \frac{b_h}{2c_h}. \quad \text{(C11)}$$

$${e_l}^* = \frac{b_l}{2c_l}. \quad \text{(C12)}$$

Notice that ${e_h}^*$ and ${e_l}^*$ are each dependent only on their own payoff parameters. This means that without considering interdependent concerns, each type's effort provision in peer learning would not be affected by their partner's ability or payoff parameters.

As already mentioned, Section C.2 assumes $\mu = 0$ to examine the effects of interdependent motives in isolation:

$$u_h(e_h|e_l) = \pi_h - x_h \cdot (\pi_h - \pi_l)^2. \quad \text{(C13)}$$

$$u_l(e_l|e_h) = \pi_l - x_l \cdot (\pi_l - \pi_h)^2. \quad \text{(C14)}$$

Each type's optimal effort provision can be derived by differentiating utilities (C13) and (C14) with respect to e_i:

$$\frac{\partial u_h}{\partial e_h} = [1 - 2x_h \cdot (\pi_h - \pi_l)](b_h - 2c_h e_h) + 2a_h x_h(\pi_h - \pi_l) = 0. \quad \text{(C15)}$$

$$\frac{\partial u_l}{\partial e_l} = [1 - 2x_l \cdot (\pi_l - \pi_h)](b_l - 2c_l e_l) + 2a_l x_l(\pi_l - \pi_h) = 0. \quad \text{(C16)}$$

For simplicity, further assume that x_h and x_l are small enough that the interdependent preferences do not reverse the intra-pair relative payoff standing, i.e., $\pi_h > \pi_l$, in equilibrium. Condition (C15) suggests that the optimal effort level of high type h (e_h^{**}) is greater than e_h^* if x_h is sufficiently large. By contrast, Condition (C16) suggests that the optimal effort level of low type l (e_l^{**}) is always lower than e_l^*. Hence, the students' interdependent motives help shrink the intra-pair performance difference through the PRA activities under certain conditions.

The size of intra-pair interim performance difference (i.e., $k_h - k_l$) and peer learning outcome:

With this framework, it can be shown that a larger intra-pair difference in the interim performance induces the high type h to put more effort in improving his/her matched low type. To show this, for simplicity, assume the following:

Assumption 1: $b_h = b_l = 0$.

Assumption 2: $c_h = c_l = c$, but $a_h > a_l$.

Assumption 1 means that effort provision by the high type in the PRA activities is purely costly without resulting in his/her own private benefits. Assumption 2 is merely a normalization: while the unit effort cost is the same for the high and low types, the impact of the PRA activities (a_h, a_l in Equations (C9) and (C10)) differs by the type.

Proposition 2: *Consider Assumptions 1 and 2. Then, the larger interim performance difference a pair has (i.e., the higher k_h, relative to k_l, the high type has), the greater academic improvement the low type can achieve thanks to the teaching provided by the high type.*

Proof: Assumption 1 implies that $e_h^* = e_l^* = 0$ from Equations (C11) and (C12), and therefore $\pi_h(e_h^*|e_l^*) = k_h > k_l = \pi_l(e_l^*|e_h^*)$.

Under these two assumptions, Condition (C15) reduces to the following:

$$f(e_h|k_h, k_l, a_h, c) \coloneqq -\mathrm{c}e_h + [2\mathrm{c}e_h x_h + a_h x_h](k_h - \mathrm{c}e_h^2 - k_l - a_h e_h) = 0 \quad \text{(C17)}$$

Appling the Implicit Function Theorem to (C17), it can be found that the larger k_h the high type h has, the greater effort level h exerts in improving the performance of the low type:

$$\frac{\partial e_h}{\partial k_h} = -\frac{\partial f/\partial k_h}{\partial f \partial e_h} = -\frac{2\mathrm{c}e_h x_h + a_h x_h}{-c + 2\mathrm{c}x_h(k_h - \mathrm{c}e_h^2 - k_l - a_h e_h) - (2\mathrm{c}e_h x_h + a_h x_h)(2\mathrm{c}e_h + a_h)}$$

$$= -\frac{2\mathrm{c}e_h x_h + a_h x_h}{-c + \frac{2\mathrm{c}^2 e_h}{2\mathrm{c}e_h + a_h} - (2\mathrm{c}e_h x_h + a_h x_h)(2\mathrm{c}e_h + a_h)}$$

(Note: the above equality is obtained by using Condition (C17))

$$= \frac{2ce_h x_h + a_h x_h}{\frac{ca_h}{2ce_h + a_h} + (2ce_h x_h + a_h x_h)(2ce_h + a_h)}$$

$$> 0. \quad \square$$