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REPLICATION SECTION

ECONOMIC TRANSITION AND GROWTH: A REPLICATION

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SUMMARY
Phillips and Sul (Journal of Applied Econometrics 2009, **24**, 1153–1185) provide an algorithm to identify convergence clubs in a dynamic factor model of economic transition and growth. We provide a narrow replication of their key results, using the open source `R` software instead of the original `GAUSS` routines. We are able to exactly replicate their results on convergence clubs, corresponding point estimates and standard errors. We comment on minor differences between their reported results and their clustering algorithm. We propose simple adjustments of the original algorithm to make manual intervention unnecessary. The adjustments allow automated application of the algorithm to other data. Copyright © 2016 John Wiley & Sons, Ltd.

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1. REPLICATION IN A NARROW SENSE

In a series of influential papers, Phillips and Sul (2003, 2007a,b, 2009) (henceforth PS) develop a dynamic factor modeling framework for testing clubs of countries for homogeneous convergence behavior (club convergence). The testing procedure is embedded within a clustering algorithm for detecting convergence clubs. Recent contributions apply the PS algorithm to various contexts; e.g. Panopoulou and Pantelidis (2009) analyze the convergence of carbon dioxide emission clubs on country-level, Bartkowska and Riedl (2012) distinguish club and conditional convergence of per capita income for European regions, and Haupt and Schnurbus (2015) analyze patterns of highly skilled employees across German regions. In this paper, we replicate the key results of Phillips and Sul (2009). We analyze their original data by using the open source statistical software `R` (R Core Team, 2015). Table I summarizes our replication of Table II in Phillips and Sul (2009).

We are able to exactly reproduce all point estimates and corresponding standard errors (up to all decimals). Clubs 1–5 of the initial classification, all merging results, and Clubs 1–4 of the final classification are identical in the respective left, middle and right column of both tables. In the following we comment on minor differences between the two tables, which occur only if the algorithm is stopped too early:

- When starting the algorithm, whether or not a country is assigned to an initial convergence club depends on the outcome of a one-sided t-test of the slope parameter γ in the 'log t'-regression in equation (18) of Phillips and Sul (2009). Each iteration of the algorithm starts with the remaining countries not already assigned to an initial convergence club in previous iterations.

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Table I. Replication of Table II in Phillips and Sul (2009) using R

Initial classification $\hat{\gamma}$ (SE of $\hat{\gamma}$)		Tests of club merging $\hat{\gamma}$ (SE of $\hat{\gamma}$)						Final classification $\hat{\gamma}$ (SE of $\hat{\gamma}$)	
Club 1 [50]	0.3816	Club 1+2						Club 1 [50]	0.3816
	(0.0411)	−0.0507*							(0.0411)
Club 2 [30]	0.2400	(0.0232)	Club 2+3					Club 2 [30]	0.2400
	(0.0348)		−0.1041*						(0.0348)
Club 3 [21]	0.1101		(0.0159)	Club 3+4				Club 3 [21]	0.1101
	(0.0324)			−0.1920*					(0.0324)
Club 4 [24]	0.1305			(0.0379)	Club 4+5			Club 4 [38]	−0.0443
	(0.0635)				−0.0443				(0.0696)
Club 5 [14]	0.1895				(0.0696)	Club 5+6			
	(0.1114)					−0.2397*			
Club 6 [11]	1.0027					(0.0612)	Club 6+7	Club 5 [11]	1.0027
	(0.1665)						−1.1163*		(0.1665)
Club 7 [2]	−0.4701						(0.0602)	Club 6 [2]	−0.4701
	(0.8417)								(0.8417)

- In contrast to Table I, Table II in Phillips and Sul (2009) reveals a divergence group consisting of 13 countries. However, another iteration of the PS algorithm using these 13 countries finds an initial convergence Club 6 consisting of 11 countries. The two remaining countries form initial convergence Club 7, as the observed $\hat{\gamma} = -0.4701$ is not significantly negative and we cannot reject the null of club convergence.

2. CLUSTERING ALGORITHM AND POTENTIAL ADJUSTMENTS

The original clustering algorithm of PS consists of four steps (cf. Phillips and Sul, 2007b, 2009). In the following, we provide a sketch of the algorithm and discuss some simple adjustments:

(1) Cross-section **sorting**:
Sort countries according to the Hodrick and Prescott (1997)-smoothed log income of the final period T.

(2) Form a **core group** of $k^* \geq 2$ countries (not already assigned to an initial convergence club in previous iterations):

(2.1) Starting with the highest income, find the first two successive countries for which the log t regression test statistic $t_{\hat{\gamma}} > -1.65$ (i.e. the corresponding null hypothesis is not rejected). If $t_{\hat{\gamma}} \leq -1.65$ for all sequential pairs of countries, exit the algorithm and 'conclude that there are no convergence subgroups in the panel' (Phillips and Sul, 2009, footnote 15).

(2.2) Start with the $k = 2$ countries identified in step (2.1), increase k proceeding with the subsequent country, perform the log t regression test. Stop increasing k if the convergence hypothesis fails to hold. The core group consists of the k^* countries that yield the highest value of the log t regression test statistic.

(3) Extend the core group to an **initial convergence club**:

(3.1) Form a complementary core group of all remaining countries not already included in the core group.

(3.2) Add one country at a time from the complementary core group (step (3.1)) to the core group (step (2)). Run the log t regression test using critical value $c^* = 0$. Form a club candidate group of all countries passing this test.

(3.3) An initial convergence club is obtained, if the convergence hypothesis holds for the core group and the club candidate group jointly using critical value -1.65. If not, repeat step (3.2) with a raised critical value c^*.

(4) **Recursion** and stopping rule (for determining initial convergence clubs):
All countries that are not part of an initial convergence club form another group. Perform the log t test for this group. If convergence cannot be rejected, the countries of the group form the last initial convergence club. Otherwise, for the remaining countries start again with step (2).

Conducting a club merging step in order to avoid 'finding more clubs than the true number' (compare Phillips and Sul, 2009, p. 1171) can be seen as an essential part of the procedure. We add the club merging as step (5) of the adjusted algorithm. It coincides with the merging conducted by Phillips and Sul (2009, Table II), where each club is merged with one other club at most.

(5) **Club merging** to determine final club structure:
Run the log t regression for all pairs of subsequent initial clubs. Merge those clubs fulfilling the convergence hypothesis jointly.

'Initial classification' in Table I here and Table II of Phillips and Sul (2009) covers steps (2)–(4) of the algorithm; the corresponding 'Final classification' is obtained after step (5).

Note that the adjusted algorithm allows for alternative club merging mechanisms. First, the merging step (5) can be iterated. Merging more than two initial convergence clubs to one final club may seem promising whenever there is a priori belief in a relatively small number of clubs. In the absence of guidelines from theory we may routinely check for further merging potential (e.g. Panopoulou and Pantelidis, 2009). Second, PS allow for merging of the divergence group with the previous club (cf. Phillips and Sul, 2009, Table II). Whenever we obtain a divergence group after steps (1)–(4) of the algorithm, exclusion of the divergent countries from the club merging step (5) may seem plausible, as the null hypothesis of convergence of these countries has already been rejected (e.g. Haupt *et al.*, 2016).

The original algorithm of PS does not ensure that the convergence hypothesis holds for each respective initial club. In step (3.2) PS make it easier to reject the convergence hypothesis by using a modified critical value of $c^* = 0$ instead of -1.65. Each country is added to the core group (obtained in step (2)) individually. However, passing an individual test using the critical value $c^* = 0$ does not guarantee that the countries of the initial convergence club pass the joint test with critical value -1.65 in step (3.3). Being aware of this fact Phillips and Sul (2007b) propose to raise the critical value c^* in step (3.2), if joint convergence in step (3.3) is rejected. Such a remedy to raise the power of the corresponding test requires manual intervention. We propose to adjust the PS algorithm by replacing step (3.3) using a data-based criterion:

(3.3*) An initial convergence club is obtained, if the convergence hypothesis holds for the core group and the club candidate group jointly using critical value -1.65. If not, start with sorting the club candidates w.r.t. decreasing $t_{\widehat{\gamma}}$ obtained in step (3.2). Add the club candidate exhibiting the highest test statistic to the core group and test whether the convergence hypothesis holds jointly using critical value -1.65. An initial convergence club is obtained by adding further club candidate group members as long as the joint convergence is not rejected.

Note that we set the default values of the `R`-arguments in a way that coincides with the original `GAUSS`-algorithm of Phillips and Sul (2009). The adjustments proposed here and implemented in our code do not alter the results for the Penn World Table data used in Phillips and Sul (2009). Of course, the results for initial convergence clubs, merging tests and final convergence clubs may differ when analyzing other data. An example is given at the end of our `R` code: the exclusion of the first period (year 1970) from the Phillips and Sul (2009) data yields a different final club composition when the adjustments are applied.

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3. CONCLUSION

We are able to exactly replicate key results of Phillips and Sul (2009) using R instead of GAUSS. We discuss and implement simple adjustments of the algorithm to allow for fully data-driven and automated identification of initial and merged convergence clubs.

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