EQUATING OR LINKING: BASIC CONCEPTS AND A CASE STUDY

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Basic Concepts

1. WHAT IS EQUATING
2. EQUATING DESIGN
3. CONFUSING TERMINOLOGIES
4. LINKING METHODS

Equating

Equating is the most clean and clear type of linking. We thus use equating to introduce many concepts relevant to other linking types later on.

- Equating is the statistical process that is used to adjust scores on test forms so that scores on the forms can be used interchangeably. Equating adjusts for differences in test form difficulty, not for differences in content.

Equating

- Properties of equating
  - Symmetry
  - Same specifications
  - Equity
  - Observed score equating
  - Group invariance

Symmetry

- This property requires that the function used to transform a score on Form X to the Form Y scale be the inverse of the function used to transform a score on Form Y to the Form X scale.

Form X	Form Y
26 ⇄	27

  - This rules out regression as an equating method.

Same specifications

- Same construct
- Similar reliability:
  - Imperfect reliability affects the equitability of scores. Adequate reliability is needed to ensure that the results associated with an equating are informative enough to be acceptable for practical use with individuals. *

- Dorans, NJ. (2004). Equating, concordance, and expectation. *Applied Psychological Measurement*, 28 (4), pp227-246.

Equity

- It must be a matter of indifference to each examinee whether Form X or Form Y is given to them.
  - ***Lord's equity property*** implies that examinees with a given true score would have identical observed score means, standard deviations, and distributional shapes of converted scores on Form X and scores on Form Y.
  - Morris suggested ***first order equity property*** or ***weak equity property*** where examinees with a given true score have the same mean converted score on Form X as they have on Form Y. Linear methods have been developed that are consistent with the first-order equity property.

Observed score equating properties

- Observed score methods do not directly consider true scores or other unobserved variables, thus less complicated.

- In observed score equating, the characteristics of score distributions are set equal for a specified *population of examinees* (Angoff, 1971).

- For the *equipercentile equating property (EEP)*, the converted scores on Form X have the same distribution as scores on Form Y. This property implies that the cumulative distribution of equated scores on Form X is equal to the cumulative distribution of scores on Form Y.

- Two other observed score equating properties must hold when the EEP hold:
  - mean equating property
  - linear equating property

Group/population invariance

- The equating relationship is the same regardless of the group of examinees used to conduct the equating. E.g. males, females.

- Lord and Wingersky (1984) indicated that, under certain theoretical conditions, true score equating methods are group invariant. However, group invariance does not necessarily hold for these methods when observed scores are substituted for true scores.

- Dorans and Holland (2000)* developed procedures and statistics for investigating group invariance.

- Dorans, N.J. & Holland, P.W. (2000). Population invariance and the equatability of tests: Basic theory and the linear case. *Journal of Educational Measurement*, 37(4), 281-306.

2 recent requirements for “good equating”

- Conditions of measurement are the same

  e.g. test with or without calculators, CR tests before and after rubric changes, rights only scoring vs. formula-scoring

- Populations taking the 2 tests are the same

Equating designs

- Random groups design
- Single group design
- Counterbalanced design
- Common item designs

Random group design

- Randomly assign forms to students
- Pros
  - Students taking only one form
  - Less time for testing
  - More forms can be equated at the same time
- Cons
  - Large sample size required
  - All forms have to be available and administered at the same time

Single group design

- The same group of students taking both forms
- Pros:
  - Statistically more powerful, need fewer subjects to achieve the same level of accuracy as random group design
- Cons:
  - Order effects: practice, fatigue
  - Security breaches

Counterbalanced design

- Examinees take both forms, some take X first, some take Y first.
- Assumption is there is no differential order effects. i.e. the effect of taking Form X after taking Form Y is the same as the effect of taking Form Y after taking Form X.
- When there is differential order effects, the data from the form taken second might need to be disregarded.

Common item design

- Types:
  - Internal anchor: a mini-version of the test that are part of the items on both forms
  - External anchor: a common measure, separate from the test, that can be used to compare the groups of test-takers
- Anchors should have the following qualities:
  - Measure the same skills and abilities that the test measures
  - Span the difficulty level of the items on both forms

Confusing Terminologies

There are many terms relevant to equating in terms of linkage type, linking method and design.

The terms for linkage type is the most confusing with some diverse opinions depending on the classification frameworks adopted.

- Linkage type
  - Classification framework
- Linking methods
- Linking Design

Confusing Terminologies

- Linkage type
  - Equating
  - Linking
  - Concordance
  - Expectation/ Projection/ Prediction
  - Calibration
  - Moderation
- Linking methods:
  - Mean
  - Linear
  - Equipercentile
- Classification systems:
  - Kolen and Brennan 2004
  - Feuer et al 1999
  - Mislevy (1992) and Linn's (1993) Taxonomy
  - Hanson et al 2001
  - Holland and Dorans 2006
- Design:
  - Random Groups Design
  - Single Group Design
  - Counterbalanced Design
  - Common Item Design

Equating--- the most stringent

Terminology

Kolen and Brennan*, Pommerich et al* and Dorans*

- measure the *same thing(same content)*
- *scores are interchangeable*
- group invariant

And/or

- *similar in difficulty by design*
- *equal reliability*

- Kolen, M.J. & Brennan, R.L. (2004). *Test equating, scaling, and linking: Methods and practice*. New York: Springer.
- Pommerich, M., etal (2004). Issues in conducting linkages between distinct tests, *Applied Psychological Measurement*, 28, 247-273.
- Dorans, N.J. (2004). Equating, concordance, and expectation. *Applied Psychological Measurement*, 28 (4), 227-246.

Linking --- diverse opinions, a general term

Terminology

- Kolen and Brennan: Linking is different from equating
  - Linking is statistical adjustments made to scores for tests that ***differ in content*** and/or difficulty, and usually both. Equating is for tests that has the same content.

- Pommerich etal *: Equating is a special form of linking
  - relating scores across ***different forms or tests***
  - In theory, ***any*** set of scores may be linked, using a variety of procedures.
  - Equating is considered the strongest type of linkage (Linn, 1993; Mislevy, 1992).

- Pommerich M., etal (2004). Issues in conducting linkages between distinct tests, *Applied Psychological Measurement*, 28, p247-273.

Concordance

Terminology

--- same linking methods as used for equating

- Hanson et al 2001
  - linking of nonequable scores using equipercentile method
- Pommerich et al 2004:
  - different constructs
  - different specifications
  - not interchangeable.
- Holland and Dorans 2006*:
  - similar constructs
  - different specifications

*Holland PW. & Dorans, NJ. (2006). Linking and equating. In R. Brennad (Ed.) *Educational Measurement*, 4th Edition.

Expectation/Prediction/Projection

--- a trinity concept?

- **Expectation** by Dorans 2004:
  - This is the least restrictive and least demanding type of linkage. The goal of predicting expected scores is to minimize the error in the predictions of one score from one or more scores. Prediction relationships are not symmetric.
  - The expected or predicted score is a concordant or equated score only when the two sets of scores are perfectly related.
  - e.g. estimation of GPA from earlier grades and standardized test scores.

Expectation/Prediction/Projection

--- How does it differ from concordance?

- **Prediction** by Pommerich et al 2004:
  - Like Concordance, prediction refers to the case in which scores are linked across tests built to ***different specifications***.
  - Unlike Concordance, prediction seeks to provide the *best estimate* of an ***individual***'s score on one measure, given that person's score on the other. Regression techniques are often used to link the scores.
  - Results from a prediction should not be used in the same manner as results from a concordance because different methods are used to conduct these linkages.

Extra Notes

- Pommerich et al (2004) demonstrated through linking of ACT and SAT I that the equipercentile method (concordance) and regression (prediction) serve different purpose, and the result should be used accordingly. While the former is more appropriate to determine comparable scores at which the same ***percentage of examinees*** score above and below the score points, the latter is more appropriate to predict an ***individual***'s score.

Expectation/Prediction/Projection

Terminology

--- How does it differ from equating or calibration?

- **Projection** by Kolen and Brennan 2004:
  - The principal distinguishing features of projections as opposed to equating or calibration, are:
    - Projection is ***unidirectional***.
    - The ***single group design*** is required.
    - There is no a priori requirement that the same constructs are being measured.
  - A projection relationship is almost always obtained via a regression (linear or non-linear).

Calibration

--- More commonly related to IRT

Terminology

- Kolen and Brennan summarized three interpretation of calibration related to *Uncommon measures (Feuer et al 1999)**as a linking type:
  - It may refer to a relationship between test forms that share ***common content*** specifications but ***different statistical specifications***. E.g. different test length.
  - It may involve test forms with ***somewhat different content*** specifications and ***perhaps different specifications***. E.g. vertical scaling for different grade levels.
  - The third connotation involves the application of a ***methodology*** (almost always ***IRT*** model) that puts all items in a domain on a ***common scale***. It is possible that a large calibrated item pool could be used to construct forms that share the same content and statistical specifications to such a degree that scores can be truly equated; often, however, the relationship between scores on such forms is better described as calibrated.

- Feuer, M.J. etal (Ed.) (1999). *Uncommon measures: Equivalence and linkage among educational tests.* Washington, DC: National Research Council.

Moderation
--- diverse definitions

Terminology

- Mislevy (1992)*:
  - The goal of moderation is to match up scores from different tests that admittedly ***do not measure the same thing.***
  - If two tests can sensibly be administered to the same students, **statistical moderation** simply applies the formulas of equating, *without claiming a measurement-theory justification.*
  - **Social moderation** calls for direct judgments about the comparability of performance levels on different assessments.
- Feuer et al (1999):
  - Moderation is the weakest form of linking. It is used when the tests have ***different blueprints*** and are given to different, ***nonequivalent groups*** of examinees. Procedures that match distributions using scores are called statistical moderation links, while others that match distributions using judgments are called social moderation links. In either case, the resulting links are only valid for making some very general comparisons (Mislevy, 1992; Linn, 1993).
- Kolen and Brennan: Concordance is a statistical moderation.

❖ Mislevy, R.J. (1999). Linking educational assessments: Concepts, issues, methods and prospects. Princeton, NJ: ETS Policy Information Center.

Mislevy 1992/Linn 1993 Taxonomy

- **Equating** --- the strongest kind of linking.
  - When a linking relationship is truly an "equating," the relationship is invariant across different populations.
- **Calibration** --- weaker than equating relationships.
  - Calibration relationships are not likely to be invariant across different populations.
- **Projection** --- a unidirectional form of linking
  - Scores on one test are predicted or "projected" from another.
- **Moderations** --- the weakest form of linking
  - Although arguments can be made that projection is a weaker form of linking than statistical moderation.
  - Two types: Statistical moderation and Judgmental or "social" moderation

Hanson et al 2001*

--- by the characteristics of the scores to be linked

Terminology

- ***Equating*** describes the linking of ***closely equable*** scores,
- ***Calibration*** describes ***weakly equable*** scores
- The terminology used to refer to linking ***nonequable*** scores depends on the method used to compute the linking function.
  - When regression is used, the resulting linkage has been termed ***prediction.***
  - When equipercentile methods are used, the linkage is termed a ***concordance.***
  - When the linkage function is computed using methods involving moderator variables, the linkage is termed ***statistical moderation.***
  - When judgments about the comparability of performance on two tests are used, the linking function is called ***social moderation.***

* Hanson BA el al. (2001) Suggestions for the evaluation and use of concordance results. *ACT Research Report Series.*

Extra Notes

Terminology

- Hanson etal's 2001 summary:
  - The term ***calibration*** is generally reserved for linkage of ***weakly equable*** scores using methodology involving ***latent variable models***. The term ***vertical equating*** or ***vertical scaling*** has been used to refer to linking weakly equable scores designed to be used at different grade levels.

Holland and Doran's System 2006*

Terminology

Linking

- Predicting: Best prediction
- Scale Aligning: Comparable Scales
  - Battery Scaling--- different constructs and a common population of examinees
  - Anchor Scaling--- different constructs and different populations of examinees
  - Vertical Scaling--- similar constructs and similar reliability, but different difficulty and populations of examinees
  - Calibration--- same constructs, different reliability, and the same population of examinees
  - Concordance--- similar constructs, difficulty and reliability, and the same population of examinees
- Test Equating: Interchangeable Scores, Same construct and the same levels of difficulty and reliability

- Holland PW. & Dorans, NJ. (2006). Linking and equating. In R. Brennad (Ed.) *Educational Measurement*, 4th Edition.

Equate, concord, or predict: evaluation steps*

1. Evaluate the similarities of the processes that produced the scores to see if the construct measured are similar.
2. Assess the strength of the empirical relationship between the scores that are to be linked. E.g. Factor analysis, Structural equation modeling, correlations.
3. Assess the degree to which a linkage is invariant across subpopulations.

- Dorans, NJ. (2004). Equating, concordance, and expectation. *Applied Psychological Measurement*, 28 (4), pp227-246.

Equating Methods

Observed scores are less complicated than true scores and are used a lot in practice for equating.

These same equating methods are also used for linking thus not restricted only for "equating" type of linkage. When that happens, "concordance table" results.

- Mean method
- Linear method
- Equipercentile method

Mean Equating (nice proof in Kolen and Brennan 2004)

- Properties of Mean Equating
  - The mean of the equated Form X scores is equal to the mean of the target Form Y scores.

$$E[m_Y(X)] = \mu(Y) \qquad \sigma[m_Y(X)] = \sigma(X)$$

  - The SD of the converted scores is the same as the SD of the scores prior to conversion.

- Problems with Mean Equating:
  - The test forms are assumed to be equally difficult or easy for all level of students.

Linear Equating

- Linear equating allows Form X to be more difficult than Form Y for low-achieving examinees but less difficult for high-achieving examinees.

- Properties of Linear Equating
  - The mean and SD of the equated Form X scores are equal to the mean and SD of the target Form Y scores.

$$E\left[l_Y(X)\right] = \mu(Y) \qquad \sigma\left[l_Y(X)\right] = \sigma(Y)$$

- Problems with Linear Equating:
  - Converted scores might fall outside the range of the observed scores
    - Truncation

Truncation

- When the converted score is beyond the possible score range, it will be set as the maximum or minimum score possible. E.g. ACCESS has a score range of 100-600. If there are 2 IPT scores converted into 601 after the linking, we can force the two scores to be 600. This is called **truncation.**

Equipercentile method

- In equipercentile equating, the interest is in finding a score y on Form Y that has the same percentile rank as a score x on Form X.

$$
\begin{aligned}
e_Y(x) &= y = Q^{-1}[P(x)], -.5 \le x \le Kx + .5 \\
&= \frac{P(x)/100 - G(y_U^* - 1)}{G(y_U^*) - G(y_U^* - 1)} + (y_U^* - .5), 0 \le P(x) < 100, \\
&= K_Y + .5, P(x) = 100,
\end{aligned}
$$

P(x) refers to the discrete cumulative distribution of x,

G(y) refers to the discrete cumulative distribution of y,

Q(y) refers to the percentile rank of Y,

Q^{-1} refers to the inverse of the percentile rank function for Form Y,

K refers to number of items on Form Y.

Properties and issues of Equipercentile Equating

- Pros:
  - Equated scores will always be within the range of possible scores under the traditional conceptualization of percentiles and percentile ranks.
- Cons:
  - Equating relationship cannot be determined outside the highest observed scores.
  - Irregular score distribution . The plot is somewhat irregular (bumpy) . These irregularities are a result of random error in estimating the equivalents. Smoothing method can lead to more regular plots and less random error.
  - Larger standard error of equating than linear equating.

Estimation problems: when there are zero frequencies

- One estimation problem that occurs in equipercentile equating is how to calculate the function P^{-1} when the frequency at some score points is zero.
  1. The convention is to average the results from using the adjacent points.
  2. Add a very small relative frequency to each score and then adjust the relative frequencies so they sum to one.
  3. Smoothing

Smoothing

- When ***sample*** percentiles and percentile ranks are used to estimate equipercentile relationships, equating often is not sufficiently precise for practical purposes because of ***sampling error***.

- Presmoothing vs. Postsmoothing
  - See the other PPT for methods and ways to evaluate smoothing results.

- However, smoothing can introduce ***systematic error*** since one more formula is enforced upon the relationship. The intent in using a smoothing method is for the increase in systematic error to be more than offset by the decrease in random error.

Pommerich et al *

--- four stages process for creating linkage

1. Choosing an appropriate linkage type and methodology
2. Linking scores and computing summary measures
3. Evaluating the quality of the linkage and determining what to report
4. Making recommendations for the interpretation and use of the linkage results

- Pommerich M., et al. (2004). Issues in conducting linkages between distinct tests. *Applied Psychological Measurement*, 18, p247-273.

NC Bridge Study

Deciding on the linking design, type and method

Bridge between IPT and ACCESS for North Carolina

- Before 2008, Ballard and Tighe's *Idea*® *Proficiency Test* (IPT) to ELLs
- Administered ACCESS for the first time in the 2008-2009 academic year
- Purpose of the Bridge Study

  To find a way to link scores on IPT and ACCESS so that it's possible to determine whether the state's annual measureable achievement objectives (AMAOs) are being met during the transition year from the IPT to ACCESS

Two procedures under consideration

- IPT and ACCESS are not constructed according to the same test specifications, the most stringent type of linking, *Equating*, is not appropriate
- We consider *Prediction* and *Concordance*

Prediction

Strong statistical method with some practical concerns

- Requires double testing: scores of both tests from the same set of students are needed
- Need a representative sample of all North Carolina ELLs, these students take both tests in a relatively short time
- Motivation concern

Concordance

- Appropriate for linking tests measuring similar constructs but constructed according to different specifications
- Proposed data collection design and statistical procedure: ***equivalent groups design linked through equipercentile methodology*** (used in the 2008 Pennsylvania Bridge Study between SELP and ACCESS)
  - *Equivalant groups design*
    - Advantage: no need of double-testing
    - Requirement: equivalence of the groups
  - *Equipercentile Linking*
    - Popular procedure with a long history
    - Assumption: the underlying ability distribution of the two different groups in the study is comparable

Testing Assumptions

- Two assumptions to be checked
  1. Similar constructs

     Are the constructs underlying the two tests whose scores will be linked in the concordance table similar?
  2. Equivalent groups

     Are the two groups of students taking the two tests approximately equivalent?

Similar constructs ?

- Compare IPT and ACCESS in terms of content and question type

	IPT	ACCESS
Academic Content Areas Whose Language Is Assessed	General and Social Language, Language Arts, Social Studies, Mathematics, and Science	Social and instructional language; Language Arts; Social Studies; Mathematics; Science
Language Domains	Listening, Reading, Writing, and Speaking	Listening, Reading, Writing, and Speaking
Administrations	Group Administration: Reading, Listening, Writing; Individual Administration: Speaking	Group Administration: Reading, Listening, Writing; Individual Administration: Speaking
Grade Levels	Pre-K-K, 1-2, 3-5, 6-8, 9-12	K, 1-2, 3-5, 6-8, 9-12
Administration Time (estimated)	Listening: 25 minutes; Reading: 45 minutes; Writing: 45 minutes; Speaking: 15 minutes	Listening: 20-25 minutes, Reading: 35-40 minutes, Writing: up to 1 hour; Speaking: up to 15 minutes

Cont'd

	IPT	ACCESS
Performance Levels	States do their own standard setting study and set their own proficiency levels (North Carolina: Novice Low, Novice High, Intermediate Low, Intermediate High, Advanced, Superior)	Entering, Beginning, Developing, Expanding, Bridging, and Reaching
Scale Score Range	0 to 1200	100 to 600
Item Formats	Multiple-choice (Listening, Reading, and part of Writing test), constructed response (Writing and Speaking)	Multiple-choice (Listening and), extended constructed response (Writing), and performance test (Speaking)
Reported Scores	Listening, Speaking, Reading, Writing, Comprehension (Listening + Reading), Overall English standard scores (Listening + Speaking + Reading + Total Writing)	Listening, Speaking, Reading, Writing, , Comprehension (Listening + Reading), Oral Language (Listening + Speaking), Literacy (Reading + Writing), Overall (Listening + Reading + Writing + Speaking)

Equivalent groups ?

- Compare the population of ELLs in North Carolina from year to year
  - in terms of its *demographic characteristics*
  - in terms of the *underlying distrubution of English language proficiency,* across the domains of listening, speaking, reading and writing
- Used IPT data from year 2006, 2007 and 2008
- Just received data for year 2009

Examples of results

- Compare demographic characteristics over the years
- 2006-2008 IPT (missing data excluded): Grades 1-2

		2006		2007		2008		2009	
		N	Percent	N	Percent	N	Percent	N	Percent
Ethnicity	American Indian	13	0.07	9	0.05	9	0.04	16	0.06
	Asian	1,717	9.64	1,859	9.55	2,071	9.59	2,783	10.39
	Hispanic	15,178	85.21	16,431	84.37	18,147	84.04	21,800	81.42
	Black	282	1.58	397	2.04	427	1.98	620	2.32
	White	457	2.57	540	2.77	589	2.73	1,015	3.79
	Multi-Racial	165	0.93	239	1.23	351	1.63	540	2.02
Gender	Female	8,556	48.05	9,355	48.04	10,402	48.17	12,882	48.11
	Male	9,251	51.95	10,120	51.96	11,192	51.83	13,892	51.89

Cont’d

- Compare distributions of English language proficiency
- Compare the cumulative frequency distribution of scale scores on each of the four domains

Figure 5.2.1B
Frequency Distribution for IPT Reading Scale Scores: 2006-2007 Grades 3-5

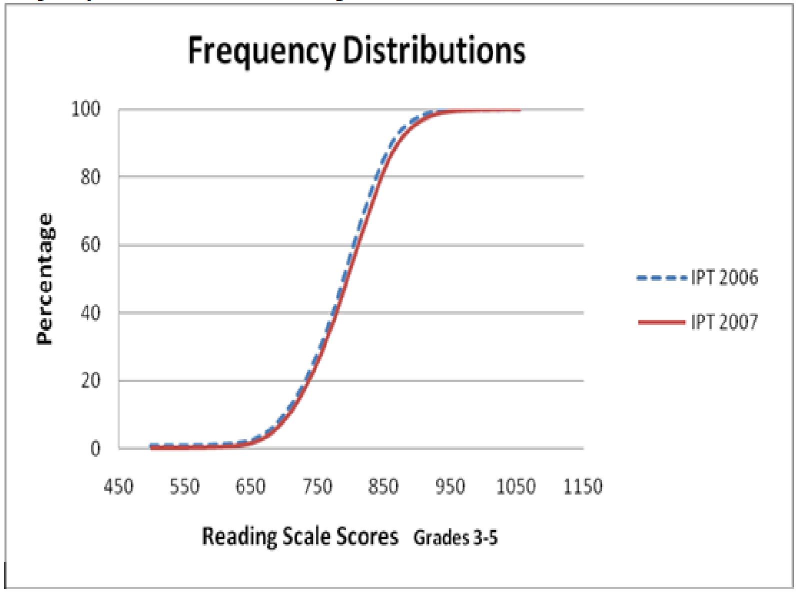
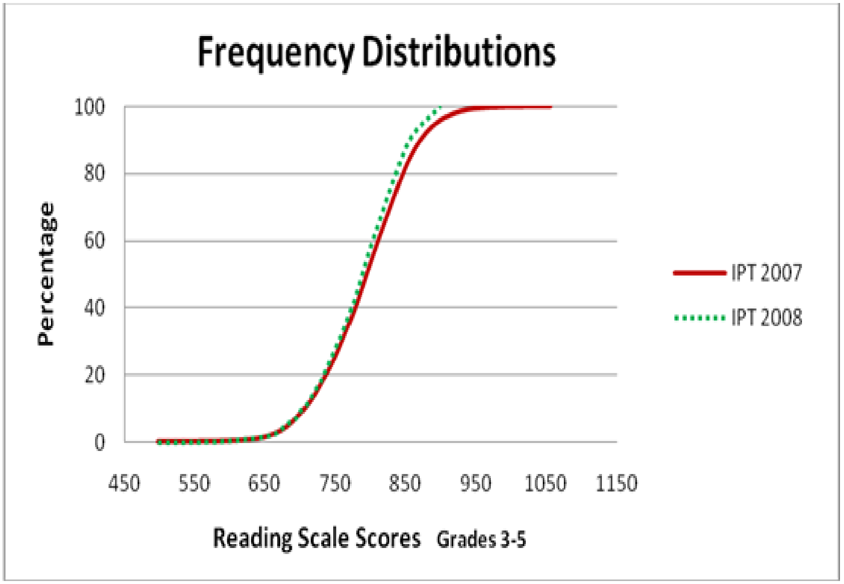


Figure 5.2.2B
Frequency Distribution for IPT Reading Scale Scores: 2007-2008 Grades 3-5



Results of testing the assumption

- Distributions of the population is demographically stable over time
- Have support for the assumption that the underlying distribution of English language proficiency in the population was the same from year to year, although the population of students changed

Control file for LEGS

1)	sc_ACCESSL12	Target form label (Form Y)
2)	sc_IPTL12	Original form label (Form X)
3)	0	Subgroups(0 if no subgroups)
4)	ACCESSfreqsL12.txt	Frequency data for Form Y
5)	IPTfreqsL12.txt	Frequency data for Form X
6)	-99	Random Group design
7)	.5 0	Range of score points and no smoothing(post)
8)	100 600 1	Valid score range, truncate rounded values

Empirical difficulties

- Missing data
  - Large missing data on demographics. Wish they are missing at random so the comparison of the populations is reasonable.
  - Missing data for the scale scores. Not bad in our case.
  - Missing data for gender. Population invariance based on subgroups Male vs. Female and the combined group can not interpreted with confidence. Not sure of the gender difference.

Equipercentile Linking Results

x	Equi_0
498	167
499	175
500	175
501	175
502	175
503	175
504	175
505	175
506	175
507	175
508	175
509	175
510	175
511	175
512	175
513	175
514	175
515	175
516	175
517	175
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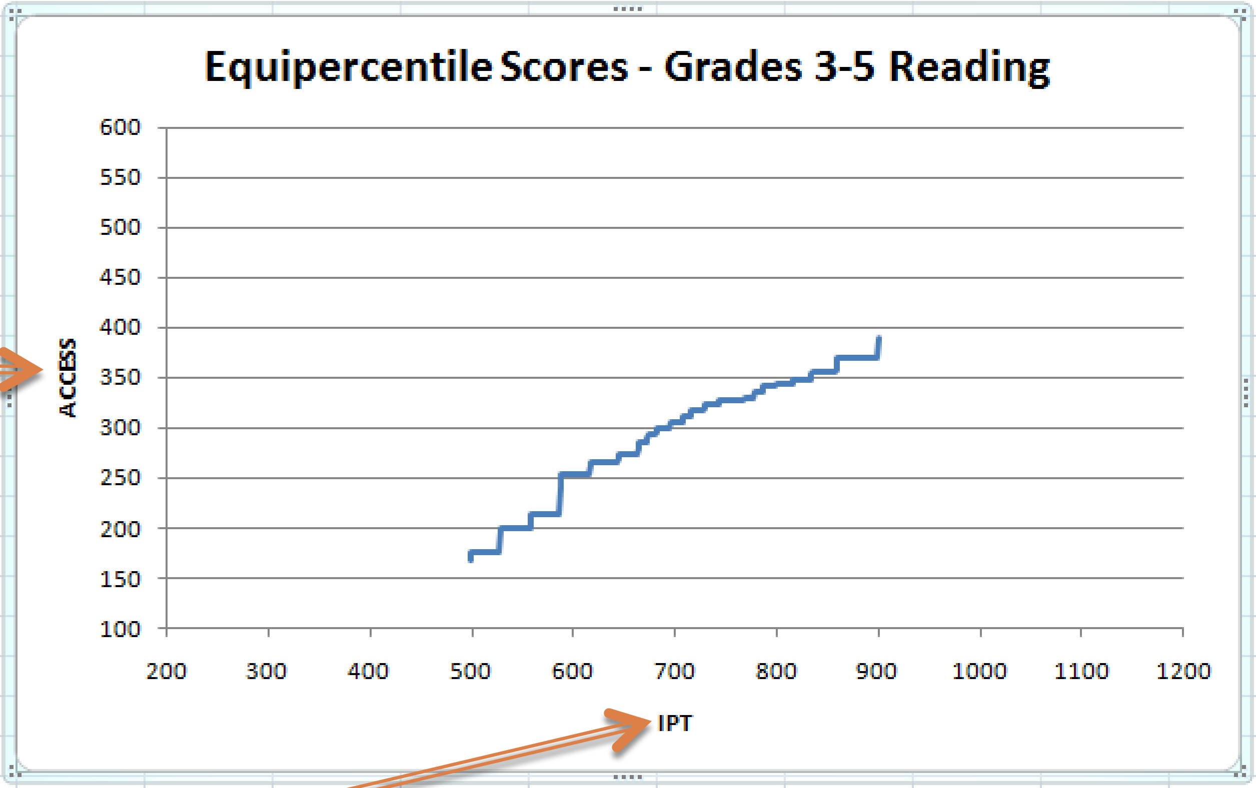
526	175
527	175
528	199



Cont'd

NC IPT

1. Novice Low
2. Novice High
3. Intermediate Low
4. Intermediate High
5. Advanced
6. Superior

ACCESS

1. Entering
2. Beginning
3. Developing
4. Expanding
5. Bridging
6. Reaching

6.4.2. Reading

Table 6.4.2A

IPT Reading Scale Score to ACCESS Reading Scale Score: Grades 3-5

IPT Reading Scale Score	IPT Proficiency Level			Predicted ACCESS Reading Scale Score	ACCESS Proficiency Level		
	Grade 3	Grade 4	Grade 5		Grade 3	Grade 4	Grade 5
498	NL	NL	NL	167	1.1	1.0	1.0
499-527	NL	NL	NL	175	1.1	1.1	1.0
528-557	NL	NL	NL	199	1.3	1.3	1.2
558-586	NL	NL	NL	213	1.5	1.4	1.3
587	NL	NL	NL	242	1.7	1.6	1.5
588-615	NL	NL	NL	253	1.8	1.7	1.6
616	NL	NL	NL	263	1.9	1.8	1.7
617-643	NL	NL	NL	266	1.9	1.8	1.7
644	NL	NL	NL	269	1.9	1.8	1.7
645-663	NH	NL	NL	274	1.9	1.9	1.8
664	NH	NL	NL	279	2.0	1.9	1.8
665-672	IL	NH	NL	285	2.3	1.9	1.9
673	IL	NH	NL	289	2.5	1.9	1.9
674-680	IL	IL	NL	293	2.6	2.1	1.9
681	IL	IL	NL	295	2.7	2.2	1.9
682-694	IL	IL	NH	300	2.9	2.4	1.9
695-698	IL	IL	IL	305	3.2	2.6	2.1
699-707	IL	IL	IL	306	3.2	2.6	2.2
708-715	IL	IL	IL	312	3.6	2.9	2.4
716-728	IH	IL	IL	318	3.9	3.1	2.6
729	IH	IL	IL	320	4.0	3.2	2.7