

Mathematical Clarification of Ricardo's Model of Comparative Advantage

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Abstract

A mathematical clarification of Ricardo's model of comparative advantage. It shows what's "counter intuitive" at first glance is intuitive after all.

Ricardo's model of comparative advantage

	<i>Good 1</i>	<i>Good 2</i>
Country 1	a_{11}	a_{12}
Country 2	a_{21}	a_{22}

Table 1: Labor Costs Per Unit

Suppose Country 1 has L_1 units of labor and allocates a portion x_1 ($x_1 \in (0,1)$) of L_1 to the production of Good 1, the rest to the production of Good 2. Also suppose Country 2 has L_2 units of labor and allocates a portion x_2 ($x_2 \in (0,1)$) of L_2 to the production of Good 1, the rest to the production of Good 2. Define Q_1 as the total output of Good 1 by Country 1 and Country 2 combined, and Q_2 as the total output of Good 2 by Country 1 and Country 2 combined:

$$\begin{cases} Q_1 = \frac{L_1 x_1}{a_{11}} + \frac{L_2 x_2}{a_{21}} \\ Q_2 = \frac{L_1(1-x_1)}{a_{12}} + \frac{L_2(1-x_2)}{a_{22}} \end{cases}$$

The lemma below gives the necessary and sufficient condition for increase in the production of either good, under the prescribed change of labor allocation.

Lemma: Suppose x_1 is increased to x'_1 and x_2 is decreased to x'_2 ,

- i) $Q'_1 > Q_1$ if and only if $\frac{L_1 a_{21}}{L_2 a_{11}} > \frac{(x_2 - x'_2)}{(x'_1 - x_1)}$;
- ii) $Q'_2 > Q_2$ if and only if $\frac{(x_2 - x'_2)}{(x'_1 - x_1)} > \frac{L_1 a_{22}}{L_2 a_{12}}$.

Proof: $Q'_1 > Q_1$ if and only if $\frac{L_1(x'_1 - x_1)}{a_{11}} > \frac{L_2(x_2 - x'_2)}{a_{21}}$. Since $x'_1 > x_1$ and $x_2 > x'_2$, simple algebra gives $\frac{L_1 a_{21}}{L_2 a_{11}} > \frac{(x_2 - x'_2)}{(x'_1 - x_1)}$. The case of $Q'_2 > Q_2$ can be proved similarly. \square

The following proposition gives the necessary and sufficient condition (the *comparative advantage condition*) for simultaneous increase in the production of both goods. Here the way to increase production is stipulated *a priori*: one country allocates more labor to the production of Good 1 and the other country allocates more labor to the production of Good 2.

Proposition 1: For given $x_1, x_2 \in (0,1)$, the following two conditions are equivalent:

- (1) there exist some $x'_1 \in (x_1, 1)$ and $x'_2 \in (0, x_2)$ such that $Q'_1 > Q_1, Q'_2 > Q_2$.
- (2) $\frac{a_{12}}{a_{11}} > \frac{a_{22}}{a_{21}}$.

Proof: (1) \Rightarrow (2). By the lemma, we have

$$\frac{L_1 a_{21}}{L_2 a_{11}} > \frac{(x_2 - x'_2)}{(x'_1 - x_1)} > \frac{L_1 a_{22}}{L_2 a_{12}},$$

Simplification and simple algebra give (2).

(2) \Rightarrow (1). (2) is equivalent to $\frac{L_1 a_{21}}{L_2 a_{11}} > \frac{L_1 a_{22}}{L_2 a_{12}}$. When we choose numbers x'_1 from the interval $(x_1, 1)$ and x'_2 from the interval $(0, x_2)$, the fraction $\frac{(x_2 - x'_2)}{(x'_1 - x_1)}$ has a range of $(0, \infty)$. So we can always find $x'_1 \in (x_1, 1)$ and $x'_2 \in (0, x_2)$ such that

$$\frac{L_1 a_{21}}{L_2 a_{11}} > \frac{(x_2 - x'_2)}{(x'_1 - x_1)} > \frac{L_1 a_{22}}{L_2 a_{12}},$$

which is equivalent to the condition $\begin{cases} Q'_1 > Q_1 \\ Q'_2 > Q_2 \end{cases}$ by the lemma. \square

The next proposition shows that under the *comparative advantage condition*, the only way to simultaneously increase the production of both goods is to allocate more labor in each country to produce the good in which that country has a comparative advantage.

Proposition 2: Under the condition $\frac{a_{12}}{a_{11}} > \frac{a_{22}}{a_{21}}$, if both $Q'_1 > Q_1$ and $Q'_2 > Q_2$ hold, then we must have $x'_1 > x_1$ and $x'_2 < x_2$.

Proof: The condition $\begin{cases} Q'_1 > Q_1 \\ Q'_2 > Q_2 \end{cases}$ is equivalent to

$$\begin{cases} \frac{L_1(x'_1 - x_1)}{a_{11}} > \frac{L_2(x_2 - x'_2)}{a_{21}} \\ \frac{L_2(x_2 - x'_2)}{a_{22}} > \frac{L_1(x'_1 - x_1)}{a_{12}} \end{cases}$$

This implies $(x'_1 - x_1)(x_2 - x'_2) > 0$. If both $(x'_1 - x_1)$ and $(x_2 - x'_2)$ are negative, we will have

$$\frac{L_1 a_{21}}{L_2 a_{11}} < \frac{(x_2 - x'_2)}{(x'_1 - x_1)} < \frac{L_1 a_{22}}{L_2 a_{12}}$$

which gives $\frac{a_{12}}{a_{11}} < \frac{a_{22}}{a_{21}}$, a contradiction. So we must have $(x'_1 - x_1) > 0$ and $(x_2 - x'_2) > 0$. \square

Intuition & Interpretation

Intuition: From the above, we can see that the labor allocation differences $(x'_1 - x_1)$ and $(x_2 - x'_2)$ jointly determine the change in outputs through the ratio $\frac{(x_2 - x'_2)}{(x'_1 - x_1)}$. Heuristically, this has the intuition that *production loss of a good in one country (due to labor reallocation) can be compensated by production increase of the same good in the other country, provided the latter has a better “exchange rate”(i.e. a comparative advantage) for this good by other goods.*

Connection with the rhetoric of comparative advantage: For Country 1,

$$1 \text{ unit of Good 2} = a_{12} \text{ units of labor} = \frac{a_{12}}{a_{11}} \text{ units of Good 1}$$

Thus $\frac{a_{12}}{a_{11}}$ has the interpretation of the opportunity cost of 1 unit of Good 2 in terms of Good 1 for Country 1. For Country 2,

$$1 \text{ unit of Good 2} = a_{22} \text{ units of labor} = \frac{a_{22}}{a_{21}} \text{ units of Good 1}$$

Thus $\frac{a_{22}}{a_{21}}$ has the interpretation of the opportunity cost of 1 unit of Good 2 in terms of Good 1 for Country 2.

The condition $\frac{a_{12}}{a_{11}} > \frac{a_{22}}{a_{21}}$ means the opportunity cost of 1 unit of Good 2 for Country 2 is lower than that of Country 1, and Country 2 therefore has a comparative advantage in the production of Good 2. Consequently, in order to maximize the total outputs of both goods, Country 1 should produce exclusively Good 1 and Country 2 should produce exclusively Good 2.

Comments

The notion of comparative advantage focuses on the *maximization of total output*; it does not explain/model the *allocation of outputs* among producers. Moreover, it ignores the benefits of *learning-by-doing* (and consequently, the potential of technology upgrade) for developing countries.

Therefore, beneath its façade of promoting economic “efficiency”, the theory of comparative advantage is in effect advocating the *status quo* of international economic order. For an eloquent critique in this regard based on historical facts and *common sense* reasoning, see (Chang 2007)¹.

¹ 中译本：(张夏准 2009)。

Appendix A. Historical Notes

Scottish economist Adam Smith used the following argument to urge the British colonies in North America not to pursue industrialization:

“It has been the principal cause of the rapid progress of our American colonies towards wealth and greatness that almost their whole capitals have hitherto been employed in agriculture. They have no manufactures, those household and coarser manufactures excepted which necessarily accompany the progress of agriculture, and which are the work of the women and children in every private family. The greater part both of the exportation and coasting trade of America is carried on by the capitals of merchants who reside in Great Britain. Even the stores and warehouses from which goods are retailed in some provinces, particularly in Virginia and Maryland, belong many of them to merchants who reside in the mother country, and afford one of the few instances of the retail trade of a society being carried on by the capitals of those who are not resident members of it. Were the Americans, either by combination or by any other sort of violence, to stop the importation of European manufactures, and, by thus giving a monopoly to such of their own countrymen as could manufacture the like goods, divert any considerable part of their capital into this employment, they would retard instead of accelerating the further increase in the value of their annual produce, and would obstruct instead of promoting the progress of their country towards real wealth and greatness. This would be still more the case were they to attempt, in the same manner, to monopolize to themselves their whole exportation trade.”

-- (Smith 1902, 55-56) Book II, Chapter V Of the Different Employment of Capitals.²

The founding fathers of the United States obviously disagreed with Smith. In his first Annual Message to Congress, January 8, 1790, President George Washington told his fellow Americans:

“A free people ought not only to be armed, but disciplined; to which end, a uniform and well digested plan is requisite: and their safety and interest require that they should promote such manufactures as tend to render them independent on others for essential, particularly for military supplies.”

-- (Washington 1790).³

A follow-up of this message is Alexander Hamilton's *Report on the Subject of Manufactures*, presented to Congress on December 5, 1791:

“Hamilton's ‘Report on Manufactures’ laid forth economic principles rooted in both the Mercantilist System of Elizabeth I's England and the practices of Jean-Baptiste Colbert of France. The principal ideas of the ‘Report’ would later be incorporated into the ‘American System’ program by Senator Henry Clay of

² “英属美洲殖民地，几乎把所有的资本都投在农业上。那里也就主要为了这个原因，才很迅速地日趋于富强。那里，除了家庭制造业和粗糙制造业（这种制造业，一定会随着农业的进步而产生，每个家庭的妇女儿童，都能经营这种工作），就没有制造业。至于输出业和航运业，则大部分由住在英国的商人投资经营。甚至有些省分，特别是维及尼亚和玛利兰，经营零售生意的店铺和栈房亦为居住在母国的商人所有。零售业不由本地商人资本经营的事例不多，这就是其中之一。假使美洲人联合起来，或用其他激烈手段，阻止欧洲制造品输入，使能够制造同种物品的本地人有独占的机会，因而使本地大部分资本，转投到制造业上来，结果将不但不能加速他们年产物价值的增进，恐怕还会加以阻碍，不但不能使其国家渐臻于富强，恐怕还会加以妨害。同样，如果他们要设法垄断全部输出业，结果也许更会如此。”——（斯密 1983, 336-337）第二篇第五章《论资本的各种用途》。

³ “自由的人民不但要有武装，还要有纪律；为此目的，一个统一的、并被良好理解的计划就有所必要；人民的安全和利益，要求他们促进制造业的发展，以使他们在必需品，尤其是军事物资上，独立于他人。”——《美国国会年鉴》，1790年1月8日，第960页。

Kentucky and his Whig Party. Abraham Lincoln, who called himself a 'Henry Clay tariff Whig' during his early years, would later make the principles outlined in the 'Report' and furthered by Clay's 'American System' program cornerstones, together with opposition to the institution and expansion of slavery, of the fledgling Republican Party.

Hamilton's ideas formed the basis for the American School of economics."

-- (Wikipedia 2014).

David Ricardo elaborated the theory of comparative advantage.⁴ Beside logical inconsistency [cf. (Baiman 2010)], Ricardo's model failed to address the issue of long-term benefits or losses from trade. As a matter of fact, Ricardo failed to mention in his article the dire consequence of the Methuen Treaty of 1703 between Great Britain and Portugal:

"Manufactures.--The Methuen Treaty of 1703 prevented the establishment of some manufacturing industries in Portugal by securing a monopoly for British textiles, and it was only after 1892 that Portuguese cotton-spinning and weaving were fostered by heavy protective duties. In 20 years these industries became the most important in the country after agriculture, the wine and cork trades and the fisheries."

[...]

*"The Cortes and the Methuen Treaty.--Pedro II, who had acted as regent for fifteen years, now became king. His reign (1683-1706) is a period of supreme importance in the economic and constitutional history of Portugal. The goldfields of Minas Geraes in Brazil, discovered about 1693, brought a vast revenue in royalties to the Crown, which was thus enabled to govern without summoning the cortes to vote supply. In 1697 the cortes met for the last time before the era of constitutional government. Even more important was the change effected when the Whig ministry of Great Britain sent John Methuen to Lisbon to negotiate a commercial agreement. The Methuen Treaty, signed on the 27th of December 1703, detached Portugal from the French alliance, and made her for more than 150 years a commercial and political satellite of Great Britain. Its most far-reaching provisions were those which admitted Portuguese wines to the British market at a lower rate of duty than was imposed upon French and German wines, in return for a corresponding preference to English textiles. **The demand for 'Port' and 'Madeira' was thus artificially stimulated to such an extent that almost the whole productive energy of Portugal was concentrated upon the wine and cork trades. Other industries, including agriculture, were neglected, and even food-stuffs were imported from Great Britain.** The disastrous economic results of the treaty were temporarily concealed by the influx of gold from Brazil, the check upon emigration from the wine-growing northern provinces, and the military advantages of alliance with Great Britain. Nor was the virtual abolition of the cortes seriously felt at first, owing to the excellent internal administration of Pedro II and his minister the duke of Cadaval."*

-- (The Encyclopedia Britannica 1911, 137, 148-149).⁵

⁴ (Ricardo 2004, 128-149) Chapter VII. On Foreign Trade. 中译本: (李嘉图 1981, 108-126) 第七章《论对外贸易》。

⁵ “制造业——1703 年的梅休因协议通过确立英国纺织品在葡萄牙的垄断地位而阻止了一些制造业在葡萄牙站稳脚跟。直到 1892 年之后, 葡萄牙的棉纺织工业才通过高额的保护性关税发展起来。20 年之后, 这些工业成为这个国家在农业、酿酒业、木塞贸易和捕鱼业之后最重要的产业。”

“议会和梅休因协议——在当了十五年摄政王之后, 佩德罗二世现在成了国王。他的统治 (1683-1706) 在葡萄牙的经济史和宪政史上是极其重要的篇章。巴西的米纳斯-吉拉斯金矿在 1693 年被发现之后, 为葡萄牙王室带来了巨大的收入。这使得王室可以不召集议会投票预算就实行统治。1697 年的葡萄牙议会集会, 是宪政政

Some modern scholars argued that the relations between England and Portugal in the 17th and 18th centuries were positive for the former country and negative for the latter, and that Portugal's past dependence on England was a major cause of its decline. Using Wallerstein's conceptual framework concerning the triadic world-scale division of labor among core states, semi-peripheral states and peripheral states, they argued that Portugal played the role of a semi-peripheral middleman, who supplied large quantities of bullion from Brazil to lay the foundation for England's commercial-industrial expansion.⁶

German economist Frederick List expressed his opinion of the Methuen treaty and of the English promotion of free trade in general:

"Of course that treaty gave to Portugal a privilege, but one merely nominal; it conferred upon the English a privilege de facto. The same spirit pervades other commercial treaties of England. Thus, cosmopolites and philanthropists in words, the English have ever been monopolists in practice."

[...]

"Thus all the English treaties of commerce exhibit a constant tendency to make every country with which they negotiate subservient to their industry and profit, offering to all apparent advantages in the purchase of agricultural products and raw materials. Their constant effort has been to ruin the industry of other countries by the cheapness of their manufactures and by the length of their credits. When they cannot secure a low tariff, they try by fraud or cunning device to elude the duties, or they organize smuggling upon a large scale; they succeeded by the first plan in Portugal, and by the second in Spain. The imposition of duties ad valorem upon importations, has been especially to their advantage; it was with a view to this policy that they recently endeavored to discredit the system of duties by weight, established by Prussia."

-- (List 1856, 134, 138-139) Book I, Chapter V Spain and Portugal.⁷

"These maxims were formerly openly avowed by all her ministers and all her members of Parliament. The ministers of George I. in 1721 frankly declared in reference to the prohibited introduction of the manufactured products of India, that a nation could not become rich and powerful but by importing raw

府时期之前的最后一次集会。更重要的，是英国的辉格党首相派遣约翰·梅休因前往里斯本谈判的一份商贸协定所带来的变化。签署于1703年12月27日的梅休因协定，使葡萄牙解除了和法国的联盟，并成为英国的商贸和政治卫星国达150年之久。这份协定中影响最深远的条款，是允许葡萄牙以低于法国和德国的关税向英国市场出口葡萄酒；作为回报，葡萄牙对英国纺织品进入葡萄牙市场提供相应的优惠。**对波特葡萄酒和马德拉葡萄酒的需求被人为地刺激到如此地步，以至于葡萄牙将几乎所有的生产能力都集中于葡萄酒和木塞贸易。其他工业和农业都被荒废掉了，连食品都需要从英国进口。**这份协议的灾难性经济后果暂时被如下因素所掩盖住了：巴西黄金的流入、对北部酿酒地区向外移民的阻止、以及和英国结盟在军事上的好处。由于佩德罗二世及其首相卡达瓦尔公爵优秀的内部管理，议会被事实上废除在起初也没有引起人们的注意。”——《不列颠百科全书》，1911年第11版，第22卷，第137、148-149页，【葡萄牙】词条。

⁶ (Lighthart 和 Reitsma 1988).

⁷ “这个条约对于葡萄牙当然是有利的，但是徒有其名；而英国人所获得的却是在作用上、效果上的实际利益，在英国人此后所订的各种商约中，都可以看到一种同样的倾向。在表面上他们总是以世界主义者、博爱主义者自居，然而就其目的与企图来说，他们实际上始终是利益垄断者。”

“现在我们可以看到，英国人所订的一切商业条约总不脱离一个倾向，要在有条约关系的一切国家扩展他们工业品的销路，给与对方的表面利益则在农产品与原料方面，他们在这些国家随时随地所努力的是用廉价物品与长期贷款手段，摧毁这些国家的工业。如果不能享有低率关税待遇，在这一点得不到便宜，他们就会想尽一切方法漏税逃税，组织大规模组织的非法买卖。我们已经看到，他们在葡萄牙行之有效的是前一办法，在西班牙实现的是后一个。在这个问题上，进口税从价的原则对他们是大有帮助的，由于这个原故，所以他们近来花了很大的气力从事宣传，要使人们相信，从量纳税的原则——象普鲁士所采用的——是要不得的。”——（李斯特 1983，61，64-65）第一编第五章《西班牙人与葡萄牙人》。

materials and exporting manufactured products. Even as late as the time of Lord Chatham and Lord North, it was maintained without hesitation in full Parliament that North America should not be allowed to manufacture a single nail.

Since the time of Adam Smith, a new maxim has been added to those mentioned: to dissemble the true policy of England by the aid of cosmopolite expressions and discussions, designed by Adam Smith to prevent foreign nations from imitating her policy.

It is a vulgar rule of prudence for him who has reached the pinnacle of power to cast down the ladder by which he mounted, that others may not follow. In this lies the secret of Adam Smith's theory, and of its cosmopolite tendencies; of his illustrious contemporary, William Pitt, as well as of all his successors in the government of Great Britain. A nation which by protective duties and maritime restrictions has built up a manufacturing industry and a merchant marine to such a point of strength and power as not to fear the competition of any other, can pursue no safer policy than to thrust aside the means of elevation, to preach to other nations the advantages of free trade, and to utter loud expressions of repentance for having walked hitherto in the way of error, and for having come so lately to the knowledge of truth."

-- (List 1856, 439-440) Book IV, Chapter I Insular Supremacy--The Continental Powers.⁸

Appendix B. Paradigm of Economic Analysis

Joseph Schumpeter explained his belief in a *facts-based* paradigm of economic analysis:

"Let us begin in a thoroughly common-sense manner. What distinguishes the 'scientific' economist from all the other people who think, talk, and write about economic topics is a command of techniques that we class under three heads: history, statistics, and 'theory.' The three together make up what we shall call Economic Analysis.

Of these fundamental fields, economic history—which issues into and includes present day facts—is by far the most important. I wish to state right now that if, starting my work in economics afresh, I were told that I could study only one of the three but could have my choice, it would be economic history that I should choose. And this on three grounds. First, the subject matter of economics is essentially a unique process in historic time. Nobody can hope to understand the economic phenomena of any, including the present, epoch who has not an adequate command of historical facts and an adequate amount of historical sense or of what may be described as historical experience. Second, the historical report cannot be purely economic but must inevitably reflect also 'institutional' facts that are not purely economic: therefore it affords the best method for understanding how economic and non-economic facts are related to one another and how

⁸ “这些准则都是过去英国的大臣和议会发言人所直认不讳的。1721年，乔治一世的大臣们当禁止印度工业品输入的时候，曾公开宣称，情况很明显，只有输入原料、输出工业品，才能使国家富强。甚至到了查坦勋爵和诺思勋爵的时候，他们还毫不迟疑地在议会公开声明，在北美洲就是一只马蹄钉也不应当允许制造。到了亚当·斯密的时候，除了我们在上面所举的一些准则以外，又初次添上了一条新的准则，这就是把英国的实际政策隐藏在亚当·斯密所发现的世界主义的措辞与论据之下，目的是在于防止外国仿效这个政策。

这本来是一个极寻常的巧妙手法，一个人当他已攀上了高峰以后，就会把他逐步攀高时所使用的梯子一脚踢开，免得别人跟着他上来。亚当·斯密的世界主义学说的秘密就在这里。他伟大的同代者威廉·庇特的、以及所有在他以后在英国执政的人的世界主义意向的秘密，也就在这里。

任何国家，如果靠了保护关税与海运限制政策，在工业与海运事业上达到了这样的高度发展，因此在自由竞争下已经再没有别的国家能同它相抗，当这个时候，代它设想，最聪明的办法莫过于把它爬上高枝时所用的梯子扔掉，然后向别的国家苦口宣传自由贸易的好处，用着那种过来人后悔莫及的语气告诉它们，它过去走了许多弯路，犯了许多错误，到现在才终于发现了自由贸易这个真理。”——（李斯特 1983，306-307）第四编第三十三章《英国优势地位与大陆国家——法国和美国》。

the various social sciences should be related to one another. Third, it is, I believe, the fact that most of the fundamental errors currently committed in economic analysis are due to lack of historical experience more often than to any other shortcoming of the economist's equipment."

-- (Schumpeter 2006, 10-11) Part I Chapter 2 Interlude I: The Techniques of Economic Analysis.⁹

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⁹ “让我们从普通常识开始：‘科学的’经济学家和其他一切对经济课题进行思考、谈论与著述的人们的区别，在于掌握了技巧或技术，而这些技术可分为三类：历史、统计和‘理论’。三者合起来构成我们的所谓‘经济分析’。

在上述基本学科中，经济史——是它造成了当前的事实，它也包括当前的事实——乃是最重要的。我愿立即指出，如果我重新开始研究经济学，而在这三门学科中只许任选一种，那么我就选择经济史。我有三条理由：首先，经济学的内容，实质上是历史长河中的一个独特的过程。如果一个人不掌握历史事实，不具备适当的历史感或所谓历史经验，他就不可能指望理解任何时代（包括当前）的经济现象。其次，历史的叙述不可能是纯经济的，它必然要反映那些不属于纯经济的‘制度方面的’事实：因此历史提供了最好的方法让我们了解经济与非经济的事实是怎样联系在一起的，以及各种社会科学应该怎样联系在一起。第三，我相信目前经济分析中所犯的根本性错误，大部分是由于缺乏历史的经验，而经济学家在其他条件方面的欠缺倒是次要的。”——（熊彼特 1991, 28-29）第一编第二章《插曲 I：经济分析的技术》。

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