On the Economics of Virtual Water Trade

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Abstract:

Virtual water trade is increasingly recognized as a useful metaphor for thinking about freshwater resources in an international context. Its legitimacy in terms of economic theory has been questioned by a number of authors, however. In this article I develop new theoretical results that place the virtual water concept on a firm economic foundation, and which correct several misconceptions within the existing literature on virtual water economics.

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1. Introduction

Allan (1997, 1998) argues that the import of water-intensive commodities by Middle Eastern countries has helped alleviate water shortages in that region, and thereby helps explain the absence of a long-predicted major conflict over water. He refers to the import of products that require a lot of water in their production as trade in "virtual water," and suggests that it provides a means to meet the growing consumption needs of countries that are otherwise short of water. This idea has gone on to stimulate much debate among scientists, academics, and government policymakers. There is much controversy among economists, in particular, regarding the language and theoretical grounding of the concept (Allan, 2003; Merrett, 2003; Ansink, 2010; Hoekstra, 2010).

Although the idea of virtual water trade is an inherently economic concept, it did not originate within the economics literature, and economists as a whole have arguably been slow to recognize and appreciate it. When economists have recognized it, however, it has often been in the form of a critique. It is the point of this article to correct some misconceptions within this literature. I ultimately show that the concept has a great deal of legitimacy when viewed from the perspective of standard international trade theory. Any empirical failures associated with the concept – summarized recently in this journal in Ansink (2010) – are due not to weak theoretical support for the concept, but to deviations from the assumptions underlying the theoretical model.

Merrett (1997) was one of the first economists to write explicitly about virtual water. Merrett argues that virtual water is merely a "metaphor," although a "powerful" and "creative" one. He uses the term metaphor because the water content of imported grain is necessarily much less than the totality of water that was used to grow the grain. The term "virtual water" does not adequately recognize this distinction, in his opinion. Writing later, Merrett (2003) recommends in even stronger terms that the phrase "the import of virtual water" not be used; rather, it should be replaced with the phrase "the import of food." In this study I will argue that this is a step too far, as it overlooks a very long tradition in international economics of viewing trade as the international exchange of the *services of factors* embodied in goods (Davis and Weinstein, 2003). Instead of saying "import of food," which eliminates any reference to water, I will argue that we should refer to virtual water trade as "import of the services of water." While a bit awkward, this is consistent with phrasing developed long ago by international trade economists who wrestled with this basic issue in another context.

Another source of contention regards how the concept of virtual water trade fits with the economic theory of comparative advantage. Wichelns (2004) criticizes Allan (2003) and Lant (2003) for drawing too close a parallel between virtual water trade and comparative advantage. Wichelns argues that the concepts are not analogous because the virtual water concept "addresses resource endowments, but it does not address production technologies or opportunity costs." In other words, a country's relative water endowment is not the only factor that influences trade patterns, even for goods that require a great deal of water in their production. In this study I argue that the virtual water concept is indeed a descendent of comparative advantage theory. Relative water endowments are indeed a potential source of comparative advantage. However, I will argue that the comparative advantage associated with relative water endowments is often *latent*. It is not so much obscured by international technology differences, as Wichelns seems to posit, but by very high trade costs in the sector with the most virtual water trade: agriculture. These all but swamp any comparative advantage that may arise from relative water endowments.

A third source of contention is associated with Ansink (2010), who argues that a number of claims made by Allan and others are only weakly supported by standard economic arguments. Indeed, Ansink provides what may be the most rigorous critique of claims that have been made in the virtual water trade literature. He does this in the context of an explicit, well-defined model: the Heckscher-Ohlin-Samuelson model of trade (Heckscher, 1919; Ohlin, 1933; Samuelson, 1949). He argues that the virtual water concept has been "incorrectly used to make certain claims that are not in line with empirical facts and standard economic theory." He suggests that the Heckscher-Ohlin trade theorem provides only very tenuous support for virtual water trade. This is important, because if this theory does not provide support, it is unlikely that any other theory will be able to.[1] In this study I challenge two of Ansink's specific claims. One of them no longer holds, for example, when one accounts for a country's spending constraint, which constrains how much a given country can possibly import from another.

In carrying out these tasks, I hope to eliminate some of theoretical uncertainty surrounding the legitimacy of virtual water trade. I demonstrate that proper application of international trade theory casts a very favorable light on the concept itself. At the same time, it must be acknowledged – as Ansink (2010) has emphasized – that the concept does not always hold up very well when tested empirically. I argue, however, that any weak

[1] This is not to suggest that the Heckscher-Ohlin model is the only model available to explore issues involving international trade and water. A potential shortcoming is its implicit assumption that there exist well-defined and enforced property rights, when this is not often the case for water. An alternative approach is offered by Chichilnisky (1994), for example, who shows how differences in property rights between two countries can create a motive for trade among otherwise identical regions.

evidence regarding the importance of water as a determinant of trade is not due to weak theoretical support, as appears to have been suggested by Ansink. Rather, any weak performance arises when real world situations deviate from the assumptions of the standard trade model.

2. The algebra of virtual water trade

I first present in formal detail how virtual water trade can be conceptualized within an economic framework, to ensure that subsequent arguments can be evaluated in proper context. The simplest way to do this is with a basic Heckscher-Ohlin trade model in which there are two countries, two factors (capital and water), and two goods. In this context, the Heckscher-Ohlin theorem is that the relatively water-abundant country will export the water-intensive good, and the relatively capital-abundant country will export the capital-intensive good. I think it critical that this is proven so that my corollaries can be properly understood.

In the tradition of international trade models, let there be two countries: Home and Foreign. I will present notation for the home country variables, with corresponding variables for the foreign country having an asterisk (*) beside it. Let c_1 and c_2 denote the quantity that home consumes of goods 1 and 2, and y_1 and y_2 denote the quantity that home produces of goods 1 and 2. There are two factor inputs that are internationally immobile: L (water) and K (capital), with associated factor prices w and r. There is perfect competition in product markets and factor markets, and identical and homothetic tastes across countries. Free trade in goods and no transportation costs ensure that prices of the two goods, p_1 and p_2, are equalized across countries, such that $p_1 = p_1^*$ and $p_2 = p_2^*$.

For goods $i=1,2$, firms choose L_i, K_i to minimize costs $wL_i + rK_i$ subject to constant-returns production technology $f_i(L_i, K_i)$. Conditional factor demands for water and capital corresponding to one unit of production are:

$$L_1/y_1 = a_{1L}(w,r) \quad L_2/y_2 = a_{2L}(w,r) \quad K_1/y_1 = a_{1K}(w,r) \quad K_2/y_2 = a_{2K}(w,r)$$

The term a_{1L}, for example, refers to the amount of water (L) needed to produce one unit of good 1. Remaining input-output coefficients are interpreted similarly. Although unit factor demands are conditional on factor prices, this dependency does not play a role in what follows, and factor price notation is henceforth suppressed. Identical technology implies that the a_{1L}, a_{2L}, a_{1K}, and a_{2K} coefficients are the same across countries.

Assuming positive production of both goods, there are two sets of equilibrium conditions. First are zero profit conditions (due to free entry):

$$a_{1L}w + a_{1K}r = p_1,$$

$$a_{2L}w + a_{2K}r = p_2.$$

Second are factor market clearing conditions:

$$a_{1L}y_1 + a_{2L}y_2 = L,$$

$$a_{1K}y_1 + a_{2K}y_2 = K.$$

For concreteness, assume that the home country is relatively water abundant:

$$\frac{L}{K} > \frac{L^*}{K^*},$$

and that good 1 is water intensive for all combinations of factor prices (no factor intensity reversals):

$$\frac{a_{1L}}{a_{1K}} > \frac{a_{2L}}{a_{2K}}.$$

Using the above framework, it can be shown that home produces relatively more good 1 than is consumed:

$$\frac{y_1}{y_2} > \frac{c_1}{c_2},$$

while in the foreign country relatively less good 1 is produced than is consumed:

$$\frac{y_1^*}{y_2^*} < \frac{c_1^*}{c_2^*}.$$

Given the goods market clearing conditions, in equilibrium we must have that home imports good 2 and exports good 1. This result is the Heckscher-Ohlin theorem, formalized by Samuelson (1949). Denoting home's exports of good 1 as X_1, and home's imports of good 2 as M_2, we have that:

$$M_2 = c_2 - y_2 > 0$$

$$X_1 = y_1 - c_1 > 0$$

The foreign country exports good 2 ($X_2^* = y_2^* - c_2^* > 0$) and imports good 1 ($M_1^* = c_1^* - y_1^* > 0$).

3. Contention one: A relatively water-abundant country can be a net water importer

The above result is just the textbook version of the Heckscher-Ohlin model, and has not been contested within the virtual water literature. Ansink (2010), however, states that the Heckscher-Ohlin theorem is "powerless when the export of virtual water embedded in the water-intensive good is offset by the import of a sufficient amount of the capital-intensive good. Although country 1 exports the water-intensive good, it would still be a net importer of virtual water." He is concerned that a small country with relative abundance in water may import such a great quantity of the non-water-intensive good 2 that it ends up being a net importer of water.

Could this really happen? I will prove that the answer is "no" unless a nation's citizens are allowed to spend more than they earn as income – a scenario that is generally ruled out in trade models, including the Heckscher-Ohlin model. This corollary is a new result, as far as I can discern, within the international trade literature, although it may not come as a great surprise to those who are steeped in that literature. In proving that the export of water embedded in the water-intensive good will never be offset by the water contained in the imported capital-intensive good, it is convenient use the concept of the "factor content" of consumption, production, and trade. This term has a long history in international economics (Davis and Weinstein, 2003), yet international trade economists have not always been explicit in what is meant by "factor content." I will use this term to refer to the total amount of a factor necessary to *produce* a good, which is likely to be more than the amount of a factor that a good contains when consumed in its final form. In the case of water, the water content of good 1 refers to the amount of water used throughout the production and distribution process to bring the product to final form.

For the home country in autarky, the water content of production is $L_1 + L_2 = L$. This is because home consumption in autarky of the two goods is $c_1 = y_1$ and $c_2 = y_2$. When we multiply y_1 and y_2 through by the amount of water necessary to produce the two goods, we get: $a_{1L}y_1 + a_{2L}y_2$, which is equal to L by the factor market clearing conditions.

Now what happens to home water consumption when there is international trade with the foreign country? We showed above that home consumption of the two goods under trade is $c_1 = y_1 - X_1$ and $c_2 = y_2 + M_2$, respectively. The water content of consumption under trade is found by multiplying through by the amount of water necessary to produce the goods:

$$a_{1L}\left(y_1 - X_1\right) + a_{2L}\left(y_2 + M_2\right) = L - a_{1L}X_1 + a_{2L}M_2,$$

where we have made use of the factor market clearing condition, again. At this point it appears that the water content of consumption under trade ($L - a_{1L}X_1 + a_{2L}M_2$) could be higher or lower than the water content of consumption with no trade (L), due to the presence of both positive and negative terms on the right-hand side. In other words, the theorem appears "powerless" at this stage, to use the adjective of Ansink (2010). However, the size of M_2 is constrained by the need to pay for the imports. In particular, there is a home budget constraint:

$$p_1c_1 + p_2c_2 = p_1y_1 + p_2y_2,$$

that says that money spent (given by the left-hand side) equals money earned (the right-hand side). An equality sign (as opposed to a less-than-or-equal sign) is used here because strict monotonicity of preferences implies that all income is spent.[2] The above relationship can be restated using our previously defined expressions for exports of good 1 (X_1) and imports of good 2 (M_2):

$$p_1X_1 = p_2M_2,$$

or simply:

$$M_2 = \frac{p_1}{p_2}X_1.$$

[2] Any unspent income could be used to buy extra consumption; with positive marginal utilities, more consumption would lead to more satisfaction. Hence it is never optimal to have unspent income.

Substituting this in for M_2 up above, the water content of consumption under trade is then:

$$L - a_{1L}X_1 + a_{2L}\frac{p_1}{p_2}X_1 \;= L + X_1\left(a_{2L}\frac{p_1}{p_2} - a_{1L}\right).$$

Again it looks as if home's water content of consumption under trade could be higher or lower than the water content of consumption with no trade. However, the zero profit conditions allow us to resolve the ambiguity. Let us ratio them as:

$$\frac{p_1}{p_2} = \frac{a_{1L}w + a_{1K}r}{a_{2L}w + a_{2K}r},$$

and substitute them in for $\frac{p_1}{p_2}$ up above. With a bit of rearranging this gives:

$$= L + X_1\frac{\left(a_{2L}a_{1K} - a_{1L}a_{2K}\right)r}{a_{2L}w + a_{2K}r}.$$

This expression as a whole is strictly less than L because the term in parenthesis is negative. It is negative because $a_{2L}a_{1K} < a_{1L}a_{2K}$ due to the assumption about which good is water intensive. The conclusion is that the water content of consumption of the country with relative abundance is *unambiguously lower* once countries start to trade. Since the water content of production must stay the same, the home country must be a net exporter of water, unambiguously.

The foreign country must then be a net importer of water, unambiguously. However much home imports good 2, it can't import so much that it becomes a net water importer. To summarize, since a country needs to pay for its imports (that is, since there is a spending constraint), Ansink's concern is unfounded.

4. Contention two: It is "confusing" to suggest that water is being traded

As noted in the introduction, Merrett (2003) calls out for an end to the term virtual water, suggesting that the phrase "import of virtual water" be replaced by "the import of food." Allan (2003) accepts this concern and agrees that, indeed, it is "confusing to suggest that water was being traded in the process of moving water intensive commodities, such as grain, from one place to another."

However, to suggest that "water is being traded" is consistent with a large branch of international trade theory that has developed over decades. The idea that goods are just bundles of the services of the factors used to make them, traces its origin at least as far back as Vanek's (1968) extension of the Heckscher-Ohlin model to multiple goods and factors. He shows that many new results are available when one works in terms of the "factor content of trade" as opposed to trade in goods themselves.[3] The factor content of a country's trade is calculated as the factor content of its consumption less the factor content of its production, where "factor content" is the total amount of a factor used in production of a good. Under this concept, international trade takes place in the *services* of factors such as capital, labor, and water.

Under the perspective of the Heckscher-Ohlin-Vanek model, we need not do as Merrett (2003) suggests, which is to replace the phrase "import of virtual water" with "the import of food." Instead of writing the "import of virtual water" we can write "import of the services of water." In this light, goods trade is but a superficial view of what is really happening: the international exchange of the services of productive factors such as capital, labor, land, and water.

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[3] When countries have more than two factors of production, it may not be possible to predict trade patterns in goods, but it is possible to predict the factor content of trade. Vanek's generalization of Heckscher-Ohlin theory allows for any number of productive factors (*F*) and goods (*N*). It requires only one additional assumption: specialization by a country in no more than *N-F* products (Vanek, 1968).

5. Contention three: There may not be a "leveling" of water around the world

Ansink (2010) observes that the Vanek theorem implies that the country that is relatively abundant in water will be a net exporter of water-intensive products. Ansink goes on to observe that a special case could occur: if Home has more water in a relative sense, yet Foreign has more water in an *absolute* sense, then Home will be exporting water to a country that has more water. For this reason Ansink suggests that a so-called "leveling" of freshwater resources around the world may not occur. He contests the claim of Allan (1997) that "the mechanisms of international trade in staple foods continue to operate with proven effectiveness to ameliorate the uneven water endowments of the world's regions." He also takes issue with Hoekstra and Hung's (2005) observation that "… high water scarcity will make it attractive to import virtual water and thus become water dependent. One would logically suppose: the higher the scarcity within a country, the more dependency on water in other countries."

The problem with Ansink's argument is that if Foreign has more water in an absolute sense but *not* a relative sense, then it must have more capital in an absolute, as well as relative sense. It is therefore essentially a "larger" country. In particular, it is a large country that has a lot of water but *consumes relatively little water compared to the rest of the world*.

It is important to develop this argument formally. The factor content of consumption for the foreign country in autarky is just its endowment of factors $\mathbf{V}^*$. Water is scarce relative to the other country (or countries). With identical homothetic preferences and identical goods prices via trade, foreign's demand for goods is just its income share of world net output: $s^{*}\mathbf{Y}^{W}$. But what is its factor content of consumption? This can be found by way of the relevant conditional factor demands summarized in the so-called techniques matrix, **A**. The factor content of consumption is simply:

$$s^{*}\mathbf{A}\mathbf{Y}^{W} = s^{*}\mathbf{V}^{W},$$

where $\mathbf{V}^{W}$ is the world endowment vector, and $\mathbf{A}\mathbf{Y}^{W} = \mathbf{V}^{W}$ due to factor market clearing. The key point is that Foreign's new water content of consumption under trade is a fraction of the world endowment of all water and capital, which is necessarily more water intensive than foreign's own factor endowment. So under trade, the large foreign country (with more water in an absolute sense) goes from consuming a relatively low amount of water (as given by an element of $\mathbf{V}^{*}$), to consuming water in the same proportion as found in the rest of the world (as given by an element of $s^{*}\mathbf{V}^{W}$).

To ensure clarity, it's useful to illustrate the principle using numbers, yet in a way that does not sacrifice its general nature. Assume that before trade, the factor content of consumption for Home happens to be four parts water to one part capital:

$$\mathbf{V} = \begin{pmatrix} L = 20 \\ K = 5 \end{pmatrix}.$$

Meanwhile, the factor content of consumption for Foreign is six parts water to nine parts capital before trade:

$$\mathbf{V}^{*} = \begin{pmatrix} L^{*} = 30 \\ K^{*} = 45 \end{pmatrix}.$$

I have made up numbers that give foreign relative water scarcity, yet absolute water abundance. After trade, both countries consume a fraction of the world endowment vector, which is one part water to one part capital:

$$\mathbf{V}^W = \mathbf{V} + \mathbf{V}^* = \begin{pmatrix} 50 \\ 50 \end{pmatrix}.$$

One part water to one part capital clearly lies in the middle of the previous factor consumption bundles of these two countries. The implication is that even though Foreign has absolutely more water in its endowment, its factor consumption profile is becoming much more like Home's. So if one looks at the water content of consumption – which is the appropriate measure in the Heckscher-Ohlin-Vanek model – then water consumption is indeed becoming more "even" around the world. On the basis of this analysis, which is entirely standard as trade theory goes, Hoekstra and Hung (2005) and Allan (1997) cannot be said to be incorrect, as Ansink has claimed.

6. Contention four: Virtual water trade is unrelated to comparative advantage

Wichelns (2004) emphasizes that virtual water trade is not the same thing as comparative advantage. However, our exposition of the Heckscher-Ohlin framework should make clear that water is a potential *source* of comparative advantage. We should not be surprised, however, if water is not a major determinant of trade patterns. Trade economists typically leave water off lists of the determinants of international trade patterns because water usually has a small share of production costs. This is true even for agricultural commodities, since rain falling on crop fields costs nothing, and irrigation water (when used) tends to be either underpriced from a societal point of view, or not priced at all.

Wichelns (2004) seems to imply that technology differences are of particular importance for explaining trade in water-intensive commodities. Certainly, international technology differences can matter quite a lot in crop agriculture, for example. There exist very restrictive technical- and policy-related barriers to international technology diffusion in this particular sector (Ruttan, 2001). But it would seem that high trade costs are even more important, as policy-related trade barriers in crop agriculture are often quite high. For example, global average bound tariffs in agriculture are roughly double those in other sectors (Reimer and Li, 2010). Reimer and Li (2010) show that freight costs are also particularly high in this sector. These barriers can only obscure the roles of water availability and technology as determinants of trade patterns.

A summary of empirical evidence on the virtual water trade hypothesis can be found in Ansink (2010). As might be expected – given the above arguments – relative water abundance does not consistently make a good predictor of trade flows in water-intensive products. However, I do not interpret this as evidence that virtual water trade has limited support from theoretical trade models. Rather, I think it simply implies that the Heckscher-Ohlin trade model does not account for everything that matters for a real world analysis of trade flows.

7. Conclusions

A number of economists have expressed reservations regarding whether virtual water trade is a legitimate economic concept and whether it accords with longstanding knowledge about the international economy and comparative advantage. I have attempted to address some of these uncertainties in this article, and hope that researchers will push forward with analysis of what might be called "trade in the services of water," or "trade in water services." This type of phrase has a long history of use by international trade economists, and recognizes that in trading goods across national borders, we are effectively trading the services of water that was used to produce the goods.

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