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Does International Trade Raise Income?
Early Studies, Critiques, and Innovations

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1 Introduction

One of the important research questions in the field of international trade is whether international trade raises income levels.[1] Theoretically, various models including the Ricardian and the Heckscher-Ohlin models demonstrate that trade increases the average income levels through the reallocation of resources to comparative advantage industries. However, it is challenging to empirically verify these theoretical results. This paper reviews early pioneering studies that addressed this research question, the critiques they received, and follow-up studies that responded to these criticisms and are now widely accepted in the literature. It summarizes the limitations of earlier work to understand how analytical methods have improved and evolved over time and to identify broader trends in the field. In doing so, the paper also seeks to draw lessons from past shortcomings.

Since the 1990s, numerous studies have examined the effects of international trade on income levels. There are mainly two reasons behind this surge. First, many countries pursued trade liberalization policies around the 1980s, 1990s, and early 2000s.[2] For instance, India opened up to trade following the 1991 financial crisis, and Indonesia took an open trade policy after the 1997 Asian financial crisis, by following the IMF's policy recommendations. Economists at the time were highly interested in the effects of these trade liberalization policies. The second reason is the rise of the endogenous growth theory. During the 1990s and 2000s, many researchers focused on theoretical models where economic growth arises endogenously from human capital accumulation and innovation. Empirical studies from this period often cite theoretical works (e.g., Romer, 1986; Lucas, 1988) and conduct empirical analyses based on the concept of "convergence" introduced by Barro and Sala-i-Martin (1992). Studying how to integrate openness into the endogenous growth model and its empirical relevance drew significant interest from both empirical researchers and theorists.

From the global and academic backgrounds mentioned above, economists have empirically investigated the relationship between trade liberalization and economic growth from the 1990s to the early 2000s. However, many early studies faced harsh criticisms, which can be broadly summarized into two points:

(1) The indicators used to measure trade liberalization did not accurately reflect the extent of trade liberalization.

(2) The studies failed to properly address potential bias caused by endogeneity.

In response to the first criticism, subsequent studies have moved away from ad hoc indicators of liberalization and instead use objective measures such as openness (the ratio of exports and imports to GDP) or tariff rates.

Regarding the second criticism, endogeneity is defined as the correlation between the explanatory variables in the regression model and the error term.[3] When endogeneity is present, ordinary least squares (OLS) estimates are biased and cannot accurately measure the effects of trade liberalization. Endogeneity can arise due to omitted variables, reverse causality, or measurement error in the explanatory variables. Therefore, to address point (2), recent studies have employed panel data analysis to control for observable and unobservable country fixed effects. Additionally, studies employing causal inference methods, such as an estimation based on a natural experiment or instrumental variables (hereafter IVs), have become the standard approach in the field.

This paper discusses the evolution of estimation methods from early to recent studies, with the aim of clarifying recent methodological developments. Specifically, it focuses exclusively on empirical research using country-level macroeconomic data and does not cover micro-level analyses based on specific country

[1] GDP per capita is often used as a measure of a country's average income level. There are studies that use the natural log of GDP per capita as the dependent variable and others that use the growth rate of GDP per capita. In this paper, the terms "GDP per capita" and "income level" are used interchangeably.

[2] It is expressed as "The Second Era of Globalization" (Hummels, 2007) and "The Great Liberalization of the 1990s" (Estevadeordal and Taylor, 2013).

[3] See page 82 of Wooldridge (2021).

episodes.[4]

Both early and recent research generally answer "Yes" to the question of whether international trade contributes to higher income levels. While studies that clarify the channels through which trade leads to higher income levels remain limited, it seems almost certain that trade raises a country's income through various channels such as specialization in comparative advantage industries, economies of scale, expanded use of cheaper imported intermediate and capital goods, intra-industry resource allocation, and the international exchange of ideas. This paper aims to summarize the big picture of the literature on this topic since the 1990s and to explore future research directions.

2 Early pioneering studies

We first discuss the methods and results of influential studies from the 1990s.[5] Although the various regression models are discussed and each equation should employ different letters for parameters, for simplicity, we use the same letters for the constant term β_0, coefficients β_1, control variables $\mathbf{X}_i$, and error terms u_i. Bold letters represent column vectors, and the prime symbol on the top right denotes the transpose of a column vector into a row vector.

2.1 International trade in the convergence literature

Empirical studies on the impact of international trade on income levels first emerged with a series of studies examining whether "convergence" in income levels is observed across domestic regions or countries. Barro and Sala-i-Martin (1992) and Mankiw et al. (1992) show that initial income levels are negatively correlated with subsequent per capita income growth rates, using cross-sectional data from US states and countries in the world, respectively. These empirical studies control for initial conditions (e.g., population growth rates, capital accumulation, and education levels) to consider situations where the economies were at the same steady state, examining "conditional convergence." Some studies also include variables representing international trade as one of the control variables to maintain constant conditions.

For example, Barro (1998) introduces the "terms of trade" (i.e., export prices divided by import prices) into the regression equation and demonstrates that an improvement in the terms of trade has a positive effect on the growth rates.[6] Barro and Sala-i-Martin (2003) include "openness" (i.e., the sum of exports and imports divided by GDP) in their regressions and show that, for developed countries, those with higher openness tend to have higher GDP growth rates.[7] While the importance of controlling for factors such as education levels and the prices of capital goods is widely discussed in these convergence studies, the role of international trade is not heavily emphasized. On the other hand, Alesina et al. (2005) demonstrate that the impact of openness on per capita income growth rates depends on the country size. They empirically show that openness has a more significant effect on growth rates in smaller countries.

2.2 Studies using the real exchange rate

Dollar (1992) uses the real exchange rate as a proxy for openness, which is referred to as "outward orientation". The real exchange rate for country i is calculated as $100 \times e_i P_i / P_{US}$, where e_i is the nominal

[4]Some prior studies focus on a specific country's trade liberalization (or trade restriction) episode (Bernhofen and Brown, 2005; Irwin, 2005; and Etkes and Zimring, 2015). Bernhofen and Brown (2005) examine the impact of Japan's opening in 1853, Irwin (2005) explores the effect of Thomas Jefferson's 1807 embargo, and Etkes and Zimring (2015) analyze the trade blockade imposed to the West Bank between 2007 and 2010. These studies tend to estimate welfare gains from trade instead of the effects on income levels. The current article does not cover these country-specific studies.

[5]Chapter 5 of Helpman (2004) also discusses some of the papers discussed in Sections 2 and 3 of this paper.

[6]See Table 1.1 on page 13 of Barro (1998).

[7]See Table 12.3 on page 522 of Barro and Sala-i-Martin (1992).

exchange rate (dollars per unit of country i's currency), P_i is the consumer price index of country i, and P_{US} is the consumer price index of the US. Dollar (1992) considers a high real exchange rate (e.g., greater than 100) as an indication that the country's price level remains elevated due to distortions caused by insufficient market openness to other countries. If this interpretation is correct, the real exchange rate should be a decreasing function of openness.[8]

Using the data of 117 countries, Dollar (1992) estimates the following equation:

$$g_i = \beta_0 + \beta_1 RexDist_i + \beta_2 RexVar_i + \mathbf{X}_i' \boldsymbol{\beta}_3 + u_i, \tag{1}$$

where g_i denotes the per capita GDP growth rate of country i during the 1976–1985 period, $RexDist_i$ denotes the average real exchange rate of country during the same period, and $RexVar_i$ denotes the variance of the real exchange rate for country i during that period. The variable $\mathbf{X}_i$ denotes a vector of control variables.[9] A high variance is interpreted as an indication of large fluctuations in the real exchange rate, which are considered to hinder growth. Although the sample period is 1976–1985, the data structure is cross-sectional, with the growth rates and average values from that period.

Table 1 summarizes the average values of $RexDist$ and $RexVar$ across different regions of the world. It shows that Asia has the lowest real exchange rate at 86, indicating a competitive environment due to lower price levels. On the other hand, Africa and Latin America have higher real exchange rates of 160 and 114, respectively, suggesting less competitive environments. Asia has a lower variance of the real exchange rate at 0.11, comparable to that of developed countries. On the other hand, Latin America has a higher value of 0.22.

Table 1: Average $RexDist$ and $RexVar$ in different regions around the world

	$RexDist$ (Distortion of real exchange rate)	$RexVar$ (Variance of distortion of real exchange rate)
Developed countries	108	0.11
Emerging countries		
Africa	160	0.15
Asia	86	0.11
Latin America	114	0.22
Europe and the Middle East	104	0.15

Note: This table comes from Dollar (1992)'s Table 3, summarizing the average values of the variables between 1976 and 1985.

Dollar (1992) estimates equation (1) and argue the following. (a) Both $RexDist_i$ and $RexVar_i$ have statistically significant negative coefficients; (b) If Latin America could maintain real exchange rate levels and variance as in Asia, its per capita GDP growth rate would increase by 2.0 percentage points; (c) If Africa could do the same, its per capita GDP growth rate would increase by 2.2 percentage points.

However, Rodriguez and Rodrik (2001) criticize Dollar (1992)'s paper on several points. First, they note that the study does not control for the effects of countries' geographic location on GDP growth rate. When introducing Latin America, Asia, and Sub-Saharan Africa dummies into the regression equation, the coefficient for $RexDist_i$ becomes statistically insignificant. Second, although the coefficient for $RexVar_i$ remains statistically significant and negative even after introducing these regional dummies, $RexVar_i$ merely captures the instability of the real exchange rate and cannot be interpreted as outward orientation. Additionally, they note that the analysis uses cross-sectional data and thus does not control for country fixed effects. They also note the possibility of reverse causality, in which GDP growth (the

[8] However, when considering to the Balassa–Samuelson effect—where countries with higher productivity have higher price levels and thus higher real exchange rates—the real exchange rate may not be the best measure of countries' "openness."

[9] It includes investment and an outlier dummy.

dependent variable) could affect the real exchange rate (the explanatory variable) in later periods of the sample.

2.3 Studies using openness constructed based on multiple indicators

Sachs and Warner (1995) use multiple indicators to define closed economies, contrary to Dollar (1992) using the real exchange rate only to define countries' outward orientation. In particular, in Sachs and Warner (1995), a country is classified as a closed economy if it meets at least one of the following conditions: (a) Non-tariff barriers are applied to at least 40% of imports; (b) The average tariff rate is 40% or higher; (c) The average black market premium for the exchange rate exceeds 40% during the 1970s and 1980s; (d) The country has a socialist economic system; (e) Exports are monopolized by a few firms. Based on these conditions, they construct a dummy variable taking unity for open economies.

Using data from 79 countries, they estimate the following regression model:

$$g_i = \beta_0 + \beta_1 D_i^{\text{Open}} + \mathbf{X}_i' \boldsymbol{\beta}_2 + u_i, \tag{2}$$

where g_i denotes the per capita GDP growth rate of country i from 1970 to 1989, and D_i^{Open} is a dummy variable that takes the value of unity if the country has an open economy. $\mathbf{X}_i$ includes control variables.[10] Results from estimating equation (2) show that the per capita GDP growth rate in open economies is approximately 2.2 percentage points higher than in closed economies.

In response, Rodriguez and Rodrik (2001) point out that the variables for (c) the black market premium and (e) export monopolization play a nearly decisive role in constructing the "open economy dummy." Based on this, they argue that the open economy dummy in Sachs and Warner (1995) likely reflects macroeconomic instability, underdeveloped social institutions, and geographic factors (such as being located in Sub-Saharan Africa) more than whether a country is truly an open economy.

2.4 Studies using multiple measures of openness

Edwards (1998) analyzes the effect of openness on growth using eight variables in addition to the index from Sachs and Warner (1995). Using data from 75 countries, Edwards (1998) estimates the following regression equation:

$$g_i = \beta_0 + \beta_1 Open_i + \mathbf{X}_i' \boldsymbol{\beta}_2 + u_i, \tag{3}$$

where g_i denotes the total factor productivity (TFP) growth rate of country i during the period 1980–1990.[11] $Open_i$ denotes an indicator of openness, which either one of the following: (a) the open economy dummy from Sachs and Warner (1995), (b) the Outward Orientation Index from the World Development Report, (c) the openness index from Leamer (1988), (d) the black market premium, (e) the average tariff rate on manufactured goods, (f) the average coverage of non-tariff barriers, (g) the Trade Distortion Index by the Heritage Foundation, (h) the trade tax ratio, and (i) the import distortion index from Wolf (1993).

The vector of control variables, $\mathbf{X}_i$, includes the natural log of GDP in 1965 and a variable measuring human capital in 1965 (average years of education). Equation (3) is estimated using weighted OLS, with weights based on PPP-adjusted GDP as of 1985. Additionally, to address the issue of endogeneity in openness, the following instrumental variables are used: (a) the TFP growth rate in the 1970s, (b) the

[10] The control variables include the log of real GDP in 1970, a dummy taking unity during periods of extreme political repression, the secondary school enrollment ratio, the initial education enrollment ratio, the share of government expenditure in GDP, the number of revolutions from 1970 to 1985, the number of assassinations as a share of population from 1970 to 1985, the relative price of investment goods, the investment-to-GDP ratio, and the population density in 1960.

[11] TFP is measured as the residual obtained by subtracting the growth of capital and labor from GDP growth. The advantage of using TFP is that it allows us to measure the impact on "productivity" after removing the contributions of capital and labor. One disadvantage is that it must assume a specific production function.

open economy dummy from Sachs and Warner (1995), (c) the ratio of imports to GDP, (d) the ratio of exports to GDP, the black market premium, the Property Rights Protection Index created by the Heritage Foundation, and (e) changes in terms of trade.[12]

Edwards (1998) finds that open economies generally have higher TFP growth rates. Rodriguez and Rodrik (2001) critique Edwards (1998) on three points. The first is that the use of GDP-weighted regression analysis seems ad hoc. The second is that the Outward Orientation Index from the World Development Report and the Trade Distortions Index by the Heritage Foundation are ad hoc variables based on subjective assessments. The third is that the instrumental variables likely do not satisfy the exclusion restriction.[13]

Using data from 81 countries from 1960 to 1985, Lee (1993) estimates the impact of average tariff rates and the black market premium on per capita GDP growth and shows that reductions in tariff rates and the black market premium promote growth. However, Rodriguez and Rodrik (2001) argue that the black market premium is not an appropriate variable and point out the possibility of reverse causality because the tariff rate data come from the 1980s.

3 Attempts to identify causal effects using cross-sectional data

We have discussed three influential papers from the 1990s—Dollar (1992), Sachs and Warner (1995), and Edwards (1998). All these papers estimate regressions where the dependent variable is either GDP per capita growth or TFP growth, and the right-hand side includes variables representing openness along with control variables.[14] The criticisms from Rodriguez and Rodrik (2001) regarding these papers primarily concern doubts about the variables used to measure openness and issues related to endogeneity. Dollar (1992) and Sachs and Warner (1995) do not consider endogeneity in their analyses. Although Edwards (1998) employs the instrumental variable method, many of the instruments used are lagged variables from the original regression. Moreover, as Rodriguez and Rodrik (2001) point out, the Property Rights Protection Index, which is one of the excluded instruments, likely does not satisfy the exclusion restrictions. This section discusses Frankel and Romer (1999), which is similar to the papers discussed so far in that it uses cross-sectional data. However, Frankel and Romer (1999) differs from these papers in that it employs a more careful identification strategy.

3.1 Identification ideas and estimation method of Frankel and Romer (1999)

Frankel and Romer (1999)'s approach is to use countries' geographical locations as exogenous factors affecting openness. For example, consider a landlocked country A, which has a low level of openness (defined as the sum of exports and imports divided by GDP), compared to a coastal country B, which has a high level of openness due to its proximity to trade partners. If all other characteristics are the same between A and B, and B's income level is higher than A's, it might be argued that the difference in openness caused by geographical factors is influencing the income level difference.

To examine the effect of openness on the income level based on this idea, the first step is to estimate

[12] All instrumental variables except for the "Property Rights Protection Index by the Heritage Foundation" and "changes in terms of trade" are based on data from the 1970s.

[13] Rodriguez and Rodrik (2001) point out that the Property Rights Protection Index likely does not satisfy the exclusion restriction, meaning that it might directly affect the TFP growth rate.

[14] Dollar (1992) and Sachs and Warner (1995) use per capita GDP growth rate as the dependent variable, while Edwards (1998) uses TFP growth rate. Frankel and Romer (1999) use the log of per capita GDP as the dependent variable. When comparing results from studies with different dependent variables, it is important to note that (a) the interpretation of coefficients vary depending on whether the dependent variable is the level (log) or the growth rate, and (b) the focus of the analysis may differ depending on whether the dependent variable is a measure of market size (GDP), per capita GDP, which accounts for population size, or TFP, which takes inputs into consideration.

the following gravity model:

$$\ln\left(\frac{T_{ij}}{GDP_i}\right) = \underbrace{\left[\ln(d_{ij}), \ln(Pop_i), \ln(Pop_j), \ln(Area_i), \ln(Area_j), (D_i^L + D_j^L)\right]}_{\mathbf{X}'_{ij}} \boldsymbol{\alpha} + e_{ij},$$

where T_{ij} denotes trade between country i and country j (the sum of exports and imports),[15] GDP_i is the GDP of country i, d_{ij} denotes the distance between the two countries, Pop_i denotes the population, $Area_i$ denotes the area, and D_i^L denotes a dummy variable that equals unity if country i is landlocked. $\boldsymbol{\alpha}$ denotes the vector of coefficient parameters and e_{ij} denotes the error term.

In the second step, based on the estimated parameters and geographical variables, the predicted values of openness are obtained as follows:

$$\widehat{Open}_i = (T_i/\widehat{GDP}_i) = \sum_{j \neq i} \exp\left(\mathbf{X}'_{ij}\widehat{\boldsymbol{\alpha}}\right),$$

where the hat symbol denotes predicted values. Since the gravity model is estimated using bilateral trade flows, the cross-sectional unit is "exporting country–importing country." In contrast, when analyzing the determinants of income levels, the cross-sectional unit is "country." Thus, the predicted value of openness for country i based on geographical factors, denoted by $\widehat{Open}_i$, is obtained by summing trade flows with all trading partners j except for its own country i.

In the third step, the following regression equation is estimated:

$$\ln(GDPpc_i) = \beta_0 + \beta_1 Open_i + \beta_2 \ln(Pop_i) + \beta_3 \ln(Area_i) + u_i, \tag{4}$$

where $\ln(GDPpc_i)$ denotes the natural log of per capita GDP; $Open_i = \sum_{j \neq i} T_{ij}/GDP_i$ denotes the actual openness. Since $Open_i$ is likely to be an endogenous variable, the predicted value based on external geographical factors, $\widehat{Open}_i$, is used as an instrumental variable.

3.2 Direction of potential bias

Before discussing results from estimating equation (4), it is important to consider the directions of potential bias that may arise in OLS estimation. Suppose that equation (4) accidentally omits an important determinant of income level, x_i, that affects income levels. In this case, the true regression equation is as follows:

$$\ln(GDPpc_i) = \beta_0 + \beta_1 Open_i + \beta_2 \ln(Pop_i) + \beta_3 \ln(Area_i) + \beta_4 x_i + \varepsilon_i.$$

Although the parameters should be represented by different letters since the variable x_i has been added, for simplicity, the same letters are used. Nevertheless, a different letter ε_i is used for the error term. The parameter estimate $\widehat{\beta}_1$ obtained by estimating equation (4) without the important variable x_i can be expressed as follows.[16]

$$\begin{aligned}
\widehat{\beta}_1 &= \beta_1 + \frac{Cov(Open_i, u_i)}{Var(\text{Open}_i)} \\
&= \beta_1 + \frac{Cov(Open_i, \beta_4 x_i + \varepsilon_i)}{Var(Open_i)} \\
&\approx \beta_1 + \frac{Cov(Open_i, \beta_4 x_i)}{Var(Open_i)}.
\end{aligned} \tag{5}$$

[15] Since EX_{ij} denotes exports from country i to country j, $T_{ij} = EX_{ij} + EX_{ji}$.

[16] See pages 84–85 of Wooldridge (2021) for details.

where β_1 denotes the true parameter (population parameter), $Cov(Open_i, u_i)$ denotes the covariance between $Open_i$ and u_i, and $Var(Open_i)$ denotes the variance of $Open_i$. The omission of x_i means that x_i is included in the error term u_i of equation (4). Therefore, we obtain the second equation in (5). When ε_i is i.i.d. (independently and identically distributed), the correlation between $Open_i$ and ε_i is zero, leading to the third equation in (5).

Equation (5) suggests that the direction of bias depends on the correlation between the "endogenous variable $Open_i$" and the "product of the omitted variable and its parameter, $\beta_4 x_i$." The direction of the bias is classified into the following four patterns based on the sign of the parameter β_4 and the sign of $Cov(Open_i, x_i)$ as shown in Table 2.[17]

Table 2: Cases for the direction of omitted variable bias

	$\beta_4 > 0$	$\beta_4 < 0$
$Cov(Open_i, x_i) > 0$	Upward bias	Downward bias
$Cov(Open_i, x_i) < 0$	Downward bias	Upward bias

Note: This table is a modified version of Table 3.2 from page 85 in Wooldridge (2021).

Frankel and Romer (1999) discuss potential omitted variables and the direction of bias. First, consider an omitted variable x_i that takes a higher value when high-quality macroeconomic policies are in place. Since high-quality macroeconomic policies would likely increase income levels, $\beta_4 > 0$, and countries with such policies might tend to adopt open economic policies, leading to $Cov(Open_i, x_i) > 0$. In this case, the estimated coefficient $\widehat{\beta}_1$ would be upwardly biased.

Second, suppose the omitted variable x_i reflects the quality of transportation infrastructure. Countries with higher income levels tend to have developed infrastructure (implying $\beta_4 > 0$), which could enhance their level of international trade ($Cov(Open_i, x_i) > 0$). Again, the estimate of $\widehat{\beta}_1$ would be subject to an upward bias.

Third, consider an omitted variable x_i that takes higher values in countries with weak domestic legal and social institutions. Such countries are often low-income countries (so $\beta_4 < 0$), and due to their weak institutions, they might rely more on tariff revenues, which could reduce their level of international trade ($Cov(Open_i, x_i) < 0$). Again, this scenario would result in an upward bias in the estimate of $\widehat{\beta}_1$. Thus, these omitted variables are likely to introduce an upward bias.

How about the possibility of reverse causality? When considering the causal relationship in the direction of "income level → international trade," we might expect that an increase in income levels could lead to an increase in international trade. For example, as income levels rise, the share of spending on imported goods might increase. If it is the case, imports would increase more than GDP. Additionally, as income levels rise, more firms may be able to cover the fixed costs of exporting, potentially leading to a greater increase in exports than GDP. If these mechanisms work, reverse causality would strengthen the positive correlation between "international trade → income level," effectively introducing upward bias.[18]

Therefore, while the estimates obtained from the IV approach may not exactly match the population parameter β_1, they should be closer to it than the OLS estimate. In other words, the IV approach should mitigate the upward bias to some extent, resulting in a smaller estimate than the OLS estimate. The next section discusses that these considerations contradict Frankel and Romer (1999)'s findings and how they reconcile the difference.

[17] $\widehat{\beta}_1 > \beta_1$ means there is upward bias. $\widehat{\beta}_1 < \beta_1$ means there is downward bias.

[18] See the first paragraph of Section E on page 391 in Frankel and Romer (1999).

3.3 Estimation results and interpretation of Frankel and Romer (1999)

Frankel and Romer (1999) estimate equation (4) using cross-sectional data from 1985. Table 3 presents results. While columns (1) and (2) show results using data from all available countries, columns (3) and (4) exclude oil-producing countries from the sample. Contrary to the theoretical discussion in the previous section, the coefficients obtained from the IV approach are larger than those obtained using OLS. According to the OLS estimates, a one percentage point increase in openness results in a 0.8% increase in income levels. In contrast, the IV estimates suggest that the same increase in openness results in a 2% to 3% increase in income levels.

How should these results be interpreted? The greater effect of trade on income implied by the IV approach cannot be explained by the logic of omitted variable and reverse causality. Frankel and Romer (1999) argue that the bias is due to measurement errors in the explanatory variables. They claim that "openness" is a proxy for all forms of international interactions that increase income levels—such as industrial specialization based on comparative advantage and the international exchange of ideas. They argue that openness is subject to measurement error when quantifying all these, which leads to attenuation bias. As a result, OLS estimates are likely to be smaller than IV estimates.

Table 3: Frankel and Romer (1999)'s results, with $\ln(GDPpc)$ as the dependent variable

	All countries		Excluding oil-producing countries	
	OLS (1)	IV (2)	OLS (3)	IV (4)
$(Exports + Imports)/GDP$	0.85 (0.25)	1.97 (0.99)	0.82 (0.32)	2.96 (1.49)
Sample size	150	150	98	98
First-stage F-stat.		13.13		8.45

Note: This table comes from Frankel and Romer (1999)'s Table 3, estimated using data from 1985. Standard errors are in parentheses. The regressions include control variables, but their coefficients are not reported in the table.

3.4 Potential flaws of Frankel and Romer (1999)

Rodriguez and Rodrik (2001) criticize Frankel and Romer (1999) by arguing that geographical characteristics (e.g., location) are direct determinants of income levels and thus do not satisfy the exclusion restriction. They point out that the geographical features of a country can influence public health, which, in turn, affects social institution quality, foreigner settlement, colonial relationships, migration patterns, and war frequency—factors that can all potentially explain differences in income levels between countries.[19] To support their argument, Rodriguez and Rodrik (2001) re-estimate Frankel and Romer's second-stage regression by including variables such as "distance from the equator," "the proportion of land in tropical regions," and "regional dummies." Their results suggest that, once these geographic variables are controlled for, the effect of openness on trade turns out to be statistically insignificant.

3.5 Follow-up studies on the robustness of Frankel and Romer (1999)

In response to the criticisms raised by Rodriguez and Rodrik (2001), Frankel and Rose (2002) revisit their analysis of the impact of adopting a common currency on international trade and income. They incorporate additional variables (e.g., distance from the equator) into the second-stage regression to

[19] See the last paragraph of page 311 of Rodriguez and Rodrik (2001).

address these concerns and show that, even after controlling for these variables, the effect of openness on income remains statistically significant.[20]

Similarly, Alcalá and Ciccone (2004) apply the IV approach of Frankel and Romer (1999) to a cross-section dataset of 138 countries from 1985. They include variables capturing the quality of social institutions from Kaufmann et al. (1999) as control variables in their regression. However, despite these additions, their results still indicate that trade positively affects income levels.[21]

Some studies expand the sample size to verify the robustness of Frankel and Romer (1999)'s results. While Frankel and Romer (1999) use 3,220 trade flows from 63 countries to estimate the gravity model, Noguer and Siscart (2005) utilize 8,906 trade flows from 97 countries.[22] Their baseline specification not controlling for variables such as "distance from the equator" suggests that a one percentage point increase in openness leads to a 0.8% and 2.6% increase in income according to OLS and IV estimates, respectively, which is similar to Frankel and Romer (1999)'s results. Additionally, they show that openness remains statistically significant even when controlling for variables such as "distance from the equator."[23] These results might suggest that Rodriguez and Rodrik (2001)'s findings of not robust effects of openness may be due to a small sample.[24]

3.6 Follow-up studies showing that the results of Frankel and Romer (1999) are not robust

Irwin and Terviö (2002) apply Frankel and Romer (1999)'s IV method to cross-sectional data from eight different years ranging from 1913 to 1990. Their findings include the following: (a) Except for 1928 during the interwar period, openness consistently led to higher income levels. (b) Similar to Frankel and Romer (1999), the IV estimates were larger than the OLS estimates. (c) The inclusion of latitude decreases the OLS estimates by half and removes the statistical significance of the IV estimate. They note that it is difficult to provide an economical interpretation of latitude. Nevertheless, they find that including latitude as a control variable significantly alters the results across all periods of the twentieth century.

Ortega and Peri (2014) also employ Frankel and Romer (1999)'s approach using data for 181 countries from 2000 and report that when controlling for "distance from the equator," the effect of openness on income levels in the IV estimates becomes zero. However, they find that openness to migration, as measured by the ratio of immigrant population, continues to positively impact income levels even after controlling for "distance from the equator."

4 Estimation with panel data

4.1 Advantages of using panel data

All the papers we have discussed so far use cross-sectional data. However, by utilizing data from multiple periods, the sample could be extended to a panel dataset. In a panel data setup, an additional

[20] Frankel and Rose (2002) do not use the exact same data as Frankel and Romer (1999), updating the original 1985 data to 1990 data and introducing additional control variables such as human capital.

[21] Alcalá and Ciccone (2004)'s primary motivation is to correct for bias arising from not considering the share of non-tradable goods, which increases as income levels rise, leading to a lower trade-to-GDP ratio. To address this issue, they measure openness using trade and PPP-adjusted GDP.

[22] Noguer and Siscart (2005)'s sample size in the second stage is almost the same as Frankel and Romer (1999). Nevertheless, Noguer and Siscart (2005) argue that using a larger sample in the gravity estimation leads to a more accurate predicted openness.

[23] They acknowledge that controlling for variables such as "distance from the equator," "the proportion of land in the tropics," and "regional dummies," reduces the size of the IV estimate by more than half.

[24] See the second paragraph of page 452 of Noguer and Siscart (2005).

subscript t indicating time (often years) in addition to country subscript i. For instance, the equation can be written as follows:[25]

$$\ln(GDPpc_{it}) = \beta_0 + \beta_1 Open_{it} + \beta_2 \ln(Pop_{it}) + \beta_3 \ln(Area_i) + \phi_i + \varepsilon_{it}. \tag{6}$$

The time-variant variables, such as GDP per capita and openness, are denoted with country subscript i and time subscript t. In contrast, time-invariant variables are denoted with the country subscript i only.[26] Furthermore, ϕ_i denotes country fixed effects.

If ϕ_i is endogenous and the regression does not take that into consideration, omitted variable bias may arise when country fixed effects are not appropriately taken into account. However, utilizing a panel dataset allows us to remove such bias. There are two methods to address the bias arising from not accounting for fixed effects: first-difference estimation and fixed effects estimation.

We begin by explaining first-difference estimation. Replacing t in equation (6) with $t-1$ leads to the following:

$$\ln(GDPpc_{i,t-1}) = \beta_0 + \beta_1 Open_{i,t-1} + \beta_2 \ln(Pop_{i,t-1}) + \beta_3 \ln(Area_i) + \phi_i + \varepsilon_{i,t-1}. \tag{7}$$

Subtracting equation (7) from equation (6) leads to following:

$$g_{it}^{GDPpc} = \beta_1 \Delta Open_{it} + \beta_2 g_{it}^{Pop} + \Delta\varepsilon_{it}, \tag{8}$$

where $g_{it}^{A} = \ln(A_{it}) - \ln(A_{i,t-1})$ denotes the growth rate (or rate of change) of variable A, which is defined in continuous time. Similarly, $\Delta Open_{it} = Open_{it} - Open_{i,t-1}$ denotes the change in openness, and $\Delta\varepsilon_{it}$ is the change in the error term. Equation (8) includes no time-invariant terms, which means that country fixed effects are taken into account. However, a downside is that, since any time-invariant variables are removed, the coefficients of such time-invariant variables cannot be estimated. This may be problematic when researchers are interested in their effects.

The fixed effects estimation is based on the same principle. Let T denote the length of the time series in the data. Summing the variables over time and dividing by T for each country i (i.e., calculating the country average over the sample period) in equation (6) yields the following equation:

$$\begin{aligned}\frac{1}{T}\sum_{t=1}^{T}\ln(GDPpc_{it}) = \beta_0 + \beta_1 \frac{1}{T}\sum_{t=1}^{T} Open_{it} + \beta_2 \frac{1}{T}\sum_{t=1}^{T}\ln(Pop_{it}) \\ + \beta_3 \ln(Area_i) + \beta_4 \phi_i + \frac{1}{T}\sum_{t=1}^{T}\varepsilon_{it}.\end{aligned} \tag{9}$$

It shows that the constant term β_0 and time-invariant variables ϕ_i remain unchanged. For any time-variant variable A_{it}, we introduce the following notation:

$$\ddot{A}_{it} = A_{it} - \frac{1}{T}\sum_{t=1}^{T} A_{it},$$

which is the deviation of the variable A for country i from its mean value (demeaned variable). Subtracting equation (9) from equation (6) leads to

$$\ln(\ddot{GDPpc}_{it}) = \beta_1 \ddot{Open}_{it} + \beta_2 \ln(\ddot{Pop}_{it}) + \ddot{\varepsilon}_{it}, \tag{10}$$

[25] See the first paragraph of page 14 of Irwin and Terviö (2002).

[26] A country's area can change for various reasons such as land reclamation projects or territorial divisions and cessions following wars. However, in most cases, it remains constant over time.

which removes time-invariant variables.

In this way, both first-difference and fixed effects estimators aim to mitigate omitted-variable bias arising from time-invariant variables. In that sense, both estimation methods are essentially the same. In fact, when $T = 2$, the first-difference estimator and the fixed effects estimator are identical.[27] When $T > 2$, the two estimators differ, and the choice of which estimator to use depends on factors such as the presence of serial correlation in the error term.[28]

A panel data analysis outperforms a cross-sectional analysis when examining the causal effect of openness on income. For example, Rodriguez and Rodrik (2001)'s criticism was about omitted variable bias arising from the omission of time-invariant factors, such as "distance from the equator," "proportion of territory in tropical zones," and "regional dummies." These time-invariant variables can be controlled for using either fixed effects or first-difference estimations.[29]

4.2 Studies using panel data

Yanikkaya (2003) conducts a panel data analysis using data from about 30 advanced countries over the 1970–1997 period to examine the effect of openness on annual GDP growth. It uses various measures of openness and trade policy variables as explanatory variables. Then, it finds a positive effect of openness on GDP growth rate. However, they also report unexpected results that higher tariff rates raise growth, contrary to their prior expectations.

Harrison (1996) estimates fixed effects models using data from 51 countries over the 1960–1988 period. The dependent variable is real GDP per capita growth. As the key explanatory variable, it uses various measures of openness such as the ratio of exports plus imports to GDP, the black market premiums, and the real exchange rate distortion index from Dollar (1992). It finds that many of the openness measures have positive effects on real GDP per capita growth.[30]

Wacziarg and Welch (2008) estimate fixed effects models using data from 136 countries over the 1950–1998 period. They use real GDP per capita growth as the dependent variable. As the key explanatory variable, they use Sachs and Warner (1995)'s openness dummy. They find that countries transitioning to open economies achieved 1.5% higher real GDP per capita growth after the transition. Although these studies control for country fixed effects, they might still face issues with potential omitted variable bias arising from time-varying confounding factors or reverse causality.[31]

4.3 Studies using dynamic panel methods

There are studies estimate dynamic panel data models using lagged variables of the explanatory variables as instruments to identify causal effects. For example, Dollar and Kraay (2004) use the identification method proposed by Arellano and Bover (1995), with the per capita GDP growth rate as the dependent variable and openness as the key explanatory variable, respectively. They apply the lagged changes of the explanatory variable as instruments in first-difference estimation and demonstrate that trade has a positive effect on per capita GDP growth.[32]

[27] See Section 14-1b on page 467 of Wooldridge (2021).

[28] According to the first paragraph on page 468 of Wooldridge (2021), if the error term $\varepsilon_{i,t}$ does not exhibit a serial correlation, the fixed effects estimator is more efficient (i.e., has smaller variance of the coefficients). However, if the error term $\varepsilon_{i,t}$ follows a random walk and $\Delta\varepsilon_{i,t}$ does not exhibit serial correlation, the first-difference estimator is more efficient.

[29] Felbermayr and Gröschl (2013) also emphasize the effectiveness of using panel data with fixed effects to control for both observable and unobservable time-invariant factors in the first paragraph of page 21 in their paper.

[30] However, some of the openness variables used by Harrison (1996) are criticized by Rodriguez and Rodrik (2001) as unreliable measures.

[31] Yanikkaya (2003) attempts to address endogeneity using the method of Frankel and Romer (1999), but the use of time-invariant geographical variables as instruments may not function appropriately in a panel setting. Harrison (1996) uses a VAR model to identify causality.

[32] The Sample includes about 100 countries from the 1980s and 1990s.

Chang et al. (2009) also base their approach on Arellano and Bover (1995)'s GMM using lagged changes of the explanatory variables as instruments to test the impact of openness on per capita GDP growth.[33] They find that the effect of trade on income growth depends on economic conditions and policies such as the level of human capital and labor market flexibility. Using Arellano and Bond (1991)'s GMM, DeJong and Ripoll (2006) employ "lagged levels of the explanatory variables" as instruments and show that reductions in tariffs increase per capita GDP growth only in high-income countries.[34]

These methods appear to address endogeneity in panel data by controlling for country fixed effects and employing lagged explanatory variables as instruments. However, Rodríguez (2007) points out that if the explanatory variables have persistency, bias induced by reverse causality cannot be addressed.[35]

4.4 Studies using identification through heteroskedasticity

Although not quite popular, there is an approach known as the "identification through heteroskedasticity." For instance, consider the following simultaneous equations:

$$\begin{aligned} y &= \beta_0 + \beta_1 x + u, \\ x &= \alpha_0 + \alpha_1 y + e. \end{aligned}$$

If the variance of the error terms of the sample, σ_e^2, can be divided into subsamples A and B (i.e., $\sigma_{Ae}^2 \neq \sigma_{Be}^2$), parameters β_1 and α_1 can be identified without using IVs (Rigobon, 2003; Rigobon and Rodrik, 2005).

Using this method, Rigobon and Rodrik (2005) show that being a democratic or rule-of-law country positively impacts GDP, while openness has a negative impact. Lee et al. (2004) also use a similar method to examine the relationship between openness, tariff rates, black market premiums, and GDP growth rates.[36] They find that more open economies have higher GDP growth rates. They also find that the "identification through heteroskedasticity" leads to a smaller effect of openness than OLS.[37]

5 Studies using panel data and instrumental variable methods

This section discusses panel data analyses that conduct a causal inference using external exogenous shocks (instead of lagged explanatory variables) as instruments. Most studies discussed in this section build upon Frankel and Romer (1999) and extend their analysis to a panel setting. The key issue when extending Frankel and Romer (1999) to a panel setting is that geographical variables cannot be used as instruments because these variables are time-invariant, which would be absorbed by country fixed effects. We discuss five time-variant instruments utilized in this context—(1) natural disasters, (2) the advent of air transport, (3) a closure and opening of a canal, (4) the advent of steamships, and (5) the Baltic Dry Index.

5.1 Studies using natural disasters as instrumental variables

Felbermayr and Gröschl (2013) conduct a panel data analysis using the data from 162 countries over the 1950–2008 period. They use "foreign" natural disasters as the source of exogenous variations in

[33] Samples of 82 countries between 1960 and 2000 were used.
[34] Samples of 60 countries between 1975 and 2000 were used.
[35] See the third paragraph on page 8 of Rodríguez (2007).
[36] Samples of 100 countries between 1961 and 2000 were used.
[37] The results are consistent with the prediction that OLS estimates tend to be upwardly biased due to omitted variables and/or reverse causality.

trade.[38] If the natural disaster in one country does not directly affect another country's income level—other than through international trade—the exclusion restriction can be considered satisfied.

The first step is to estimate the following equation:[39]

$$Open_{ijt} = \exp\left\{\alpha_1 N_{jt} + \mathbf{X}'_{ijt}\boldsymbol{\alpha}_2 + v_i + v_j + v_t\right\} + e_{ijt}. \tag{11}$$

The variable $Open_{ijt} = (EX_{ijt} + EX_{jit})/GDP_{it}$ denotes the sum of exports from country i to country j in year t, where the of exports from i to j EX_{ijt} and exports from j ti EX_{jit} is divided by GDP_{it}. The variable N_{it} denotes the number of major natural disasters in country i in year t.[40] $\mathbf{X}_{ijt}$ is a vector of control variables, v_i denotes country fixed effects, v_t denotes year fixed effects, and e_{ijt} denotes the error term. Note that $Open_{ijt}$ captures the openness of country i regarding its trading partner j since the denominator is i's GDP instead of j's.[41] Exogenous variations in openness, induced by natural disasters in trading partner j, N_{jt}, are used to construct the instrument.

The second step is to find the predicted openness using the coefficients from (11), as follows:

$$\widehat{Open}_{it} = \sum_{j\neq i}\widehat{Open}_{ijt} = \sum_{j\neq i}\exp\left(\widehat{\alpha}_1 N_{jt} + \mathbf{X}'_{ijt}\widehat{\boldsymbol{\alpha}}_2\right).$$

The third step is to estimate the following equation using the IV approach.

$$\ln(GDPpc_{it}) = \beta_0 + \beta_1\,Open_{it} + \beta_2\ln(Pop_{it}) + \beta_3 N_{it} + \beta_4 N_{it-1} + \theta_i + \theta_t + u_{it}. \tag{12}$$

Since the actual openness $Open_{it} = \sum_{j\neq i}(EX_{ijt} + EX_{jit})/GDP_{it}$, is endogenous, exogenous variations in the predicted openness $\widehat{Open}_{it}$ caused by foreign natural disasters, are utilized to find causal effects. The model controls for population $\ln(Pop_{it})$, the number of disasters in the same country N_{it}, and its lagged value N_{it-1}. The variable θ_i denotes country fixed effects, θ_t denotes year fixed effects, and u_{it} denotes the error term.

Table 4 summarizes results. Results based on the full sample and on the sample excluding oil-producing countries both show that the IV estimates exceed the OLS estimates. This result, $\widehat{\beta}_1^{IV} > \widehat{\beta}_1^{OLS}$, is similar to Frankel and Romer (1999)'s results. Table 4 shows that a one percentage point increase in openness increases income levels by 1.3% to 1.8%. This result is essentially based on time-series variation in the data. As a result, it is difficult to compare this estimate with Frankel and Romer (1999)'s estimate, which is based on cross-sectional variations. Nevertheless, the estimated effects are not largely different from those in Frankel and Romer (1999).

[38] Dorn et al. (2022) apply the method used by Felbermayr and Gröschl (2013) to 139 countries over the 1970–2014 period to examine the impact of international trade on income inequality (measured by the Gini coefficient).

[39] This is a simplified version of equation (4) of Felbermayr and Gröschl (2013). This equation is estimated using PPML.

[40] A "major natural disaster" is defined as an event that meets any of the following criteria: (a) results in over 1,000 deaths, (b) causes injuries to over 1,000 people, or (c) affects more than 100,000 people.

[41] Note that $Open_{ijt} = (EX_{ijt} + EX_{jit})/GDP_{it} \neq (EX_{jit} + EX_{ijt})/GDP_{jt} = Open_{jit}$.

Table 4: Felbermayr and Gröschl (2013)'s results, with ln(*GDP per capita*) as the dependent variable

	All countries		Excluding oil-producing countries	
	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)
$(Exports + Imports)/GDP$	0.40	1.76	0.55	1.25
	(0.09)	(0.49)	(0.12)	(0.18)
Sample size	1312	1312	919	919
Number of countries	162	162	94	94
First-stage F-stat.		6.99		31.41

Note: This table comes from Felbermayr and Gröschl (2013)'s Table 4, presenting estimates based on 5-year averages of data from 1950–2008, covering 12 time points. Standard errors are in parentheses. While the regressions includes control variables and fixed effects, these are not reported in the table.

5.2 Studies using time-varying geography as instrumental variables

5.2.1 The advent of air transport

Feyrer (2019) examines the impact of international trade on income levels using panel data from 101 countries covering the 1950–1995 period, addressing the criticisms raised by Rodriguez and Rodrik (2001). Feyrer (2019) uses a reduction in transportation distance brought by the advent of air transport as the source of exogenous variations in trade. Between 1955 and 2004, air transport costs decreased by a factor of 10. Despite the fact that air transport hardly existed before 1960, it grew to account for more than half of U.S. exports by value by 2004 (Feyrer, 2019). Although the introduction of air transport may seem like a global macro shock affecting all countries uniformly, its impact varies significantly across countries due to differences in geographical locations. As an example, Feyrer (2019) mentions that the sea distance between Japan and Germany is 12,000 miles, whereas the air distance is less than 5,000 miles. While some country pairs—e.g., the U.S. and Germany—have little difference between sea and air transport distances, others experience a significant reduction in transportation distance due to the introduction of air transport. Therefore, the extent of this reduction varied substantially by country, depending on its geographical location. Both the advent of air transport and countries' geographical locations are considered largely exogenous, making them valid instruments for estimating the impact of trade on income levels.

The first step is to estimate the following equation:

$$\ln(T_{ijt}) = \beta_0 + \beta_t^{\text{Sea}} \ln\left(d_{ij}^{\text{Sea}}\right) + \beta_t^{\text{Air}} \ln\left(d_{ij}^{\text{Air}}\right) + \nu_{ij} + \nu_t + e_{ijt},$$

where T_{ijt} denotes trade values between countries i and j (i.e., the sum of bilateral trade values)[42], d_{ij}^{Sea} denotes sea distance between i and j, d_{ij}^{Air} denotes air distance between them, v_{ij} denotes the fixed effects for country pairs, v_t denotes the year fixed effects, and e_{ijt} denotes the error term.[43] This equation is estimated separately for each year t, allowing the parameters β_t^{Sea} and β_t^{Air} to vary over time. The advent of air transport and the associated reduction in air transport costs affect the parameters β_t^{Sea} and β_t^{Air}. Feyrer (2019) shows that after 1960, trade between countries with shorter air distances increased, leading to a rise in $|\widehat{\beta}_t^{\text{Air}}|$ and a decrease in $|\widehat{\beta}_t^{\text{Sea}}|$.

As the second step, the time-varying "elasticities of trade with respect to distance" are used to isolate the exogenous variation in trade. In particular, the predicted trade values are obtained using the following

[42] Let EX_{ijt} denote exports from country i to country j. Then $T_{ijt} = EX_{ijt} + EX_{jit}$.

[43] Since country pair fixed effects v_{ij} are included in the regression, the absolute values of the coefficients β_t^{Sea} and β_t^{Air} for distance variables $\ln(d_{ij}^{\text{Sea}})$, $\ln(d_{ij}^{\text{Air}})$ cannot be obtained. Instead, only the relative changes over time can be obtained. Additionally, Feyrer (2019) estimates another regression with country fixed effects v_i and v_j (instead of v_{ij}).

equation:

$$\widehat{T}_{it} = \exp\left(\widehat{v}_t\right) \sum_{j \neq i} \exp\left(\widehat{\beta}_t^{\text{Sea}} \ln(d_{ij}^{\text{Sea}}) + \widehat{\beta}_t^{\text{Air}} \ln(d_{ij}^{\text{Air}}) + \widehat{v}_{ij}\right).$$

The third step is to estimate the following equation using $\ln(\widehat{T}_{it})$ as an instrument for $\ln(T_{it})$.[44]

$$\ln(GDPpc_{it}) = \beta_0 + \beta_1 \ln(T_{it}) + \theta_i + \theta_t + u_{it}, \tag{13}$$

where $\ln(GDPpc_{it})$ denotes the natural log of per capita GDP, and $T_{it} = \sum_{j \neq i} T_{ijt}$ denotes the actual openness, which is likely to be endogenous. Therefore, the predicted value from the second step, $\widehat{T}_{it}$, is used as an instrument. Feyrer (2019) validates the choice of the explanatory variable $\ln(T_{it})$ instead of T_{it}/GDP_{it}.

> Unlike in Frankel and Romer (1999), the key right-hand side variable is the log of trade, not trade as a percentage of GDP (trade share). The use of trade share as a right-hand side variable is inherently problematic because trade share is a function of trade, GDP per capita, and population. In using trade share, GDP per capita appears on both sides of the regression, making the interpretation of the coefficient problematic. Imagine that the elasticity of income with respect to trade were one. A shock to trade would result in no movement in trade share.

The sample excludes oil-exporting countries and landlocked countries where maritime distances cannot be defined, resulting in a total of 101 countries.

Table 5 summarizes results. The OLS result suggests that a 1% increase in trade leads to a 0.446% increase in per capita income. The IV estimate is slightly larger, with an elasticity of 0.459. Both the OLS and IV estimates are statistically significant at the 1% level. Feyrer (2019) also constructs several different IVs and adjusts the fixed effects slightly, presenting multiple estimates. The IV estimates of the income elasticity with respect to trade range from 0.50 to 0.75.[45]

However, Feyrer (2019) estimates may overstate the impact of trade on income levels for two reasons.[46] First, the increase in trade induced by air transportation may vary with industrial structure. In this case, the IV estimate captures the effect in countries where trade was strongly influenced by the advent of air transportation. This corresponds to the local average treatment effect (LATE), which may exceed the true coefficient. Second, the exclusion restriction may not hold strictly. Air transportation likely facilitated not only trade but also cross-border mobility of individuals and firms. If this increased immigration and foreign direct investment and thereby affected income, the IV estimate would reflect broader globalization effects beyond trade alone.

5.2.2 The closure and reopening of the Suez Canal

Feyrer (2021) utilizes the closure and reopening of the Suez Canal as a natural experiment to estimate the effects of trade on income levels.[47] When the Third Middle East War began on June 5, 1967, Egypt

[44] Although Feyrer (2019) constructs multiple instruments, this section discusses equation (12) of Feyrer (2019) only.

[45] As discussed earlier, the regression specification in Feyrer (2019) differs from that in Frankel and Romer (1999), so a direct comparison of their estimates is not feasible. However, using Donaldson's (2015) method to convert the figures into comparable terms, Feyrer shows that the 0.50–0.75 range observed in his study is equivalent to the 1.8–5.5 range in Frankel and Romer (1999). Given that Frankel and Romer (1999) reported an estimate of 2, Feyrer concludes that his results are broadly consistent with those of Frankel and Romer (1999).

[46] For details on the first reason discussed below, see the second paragraph of Section C on page 6 of Feyrer (2019). For details on the second reason, see the last paragraph of Section B on page 5.

[47] Other studies that have used fluctuations in shipping routes as natural experiments include Bekkers et al. (2018) and Maurer and Rauch (2023). Bekkers et al. (2018) utilize the opening of the Northern Sea Route due to the melting of Arctic ice as a natural experiment to examine its impact on the welfare of various countries. Maurer and Rauch (2023) investigate the effects of the 1914 opening of the Panama Canal on the population of different counties in the US. Because these studies use welfare and population as outcome variables and employ model-based approaches, the current article does not cover them.

Table 5: Feyrer (2019)'s results, with $\ln(GDPpc)$ as the dependent variable

	OLS	IV
	(1)	(2)
$\ln(Exports + Imports)$	0.446	0.459
	(0.041)	(0.097)
Sample size	774	774
Number of countries	101	101
First-stage F-stat.		30.5

Note: This table comes from columns (1) and (4) of Table 4 in Feyrer (2019), estimated using data from 1950 to 1995 at five-year intervals, covering 10 periods. Standard errors are in parentheses. The regressions include control variables and fixed effects, but these are not reported from the table.

closed the Suez Canal, and it remained closed for a full eight years until it was reopened on June 5, 1975. The closure and reopening of the Suez Canal caused fluctuations in maritime transport distances, which can be considered an exogenous shock, making it a valid instrument.

The first step is to estimate the following regression model:

$$\ln(T_{ijt}) = \beta_0 + \beta_1 \ln(d_{ijt}) + v_{ij} + v_t + e_{ijt}, \tag{13}$$

where T_{ijt} denotes the sum of the bidirectional trade between countries i and j, and d_{ijt} denotes maritime distance between i and j in year t. While this distance typically remains constant over time, it undergoes discrete changes in 1967 and 1975, which is why it is indexed by t.

The second step is to obtain the following prediction:

$$\widehat{T}_{it} = \exp(\widehat{v}_t) \sum_{j \neq i} \exp\left(\widehat{\beta}_1 \ln d_{ijt} + \widehat{v}_{ij}\right).$$

The third step is to estimate equation (13) using $\ln(\widehat{T}_{it})$ as an instrument for $\ln(T_{it})$. It uses data from 80 countries, excluding oil-producing and landlocked countries, from 1960 to 1984.

Table 6 summarizes results. The IV and OLS estimates suggest that a 1% increase in trade increases per capita income by 0.30% and 0.227%, respectively. Unlike the results discussed earlier, the IV estimate is greater than the OLS estimate. Additionally, the IV estimate is smaller than that reported by Feyrer (2019). There are two reasons for the smaller estimates. First, since the exogenous variation arises from the canal's closure and reopening, it does not include the effects of air transport (Feyrer, 2021).[48] Second, while Feyrer (2019) uses data at five-year intervals to estimate long-term effects, Feyrer (2021) uses annual data to estimate short-term effects.[49] Given that the estimate in Feyrer (2021), which relies only on variation in maritime transport, is about half of the estimate based on variation in both maritime and air transport, the effects of international interactions beyond merchandise trade appear to account for roughly half of the total impact.[50]

5.2.3 The advent of steamships

Pascali (2017) investigates the impact of trade on income levels using a reduction in maritime transport time due to the introduction of steamships as an instrument. The transition from sailing ships to steamships began around 1865, and by 1875 most maritime transport was conducted using steamships.

The effect of this transition on shipping time was heterogeneous across countries, depending on their geographical location and prevailing wind patterns. Pascali (2017) explains that, since the wind patterns

[48] See the text on the right side of page 9 of Feyrer (2021).
[49] See the second paragraph on the left side of page 2 of Feyrer (2021).
[50] See the last text of page 9 of Feyrer (2019).

TABLE 6: Feyrer (2021)'s results, with $\ln(GDPpc)$ as the dependent variable

	OLS	IV
	(1)	(2)
$\ln(Exports + Imports)$	0.300	0.227
	(0.052)	(0.083)
Sample size	1771	1771
Number of countries	80	80
First-stage F-stat.		14.8

Note: This table comes from column (1) of Tables 4 and 5 in Feyrer (2021), estimated using data for each year from 1960 to 1984, covering 25 periods. Standard errors are in parentheses. The regressions include control variables and fixed effects, but these are not reported in the table.

in the North Atlantic are clockwise, the round-trip time from Lisbon, Portugal, to Cape Verde (approximately 2,800 km to the west of Africa) and from Lisbon to El Salvador (approximately 8,200 km) was nearly the same when using sailing ships. However, with the advent of steamships, the round-trip time between Lisbon and Cape Verde was significantly reduced. Pascali (2017)'s idea was to use different reductions in trade costs across countries identify the impact of trade on income levels.

The first step is to estimate the following equation:

$$\ln(EX_{ijt}) = \beta_t^{\text{Steam}} \ln\left(time_{ijt}^{\text{Steam}}\right) + \beta_t^{\text{Sail}} \ln\left(time_{ijt}^{\text{Sail}}\right) + \mathbf{X}_{ijt}'\beta + v_t + e_{ijt},$$

where EX_{ijt} denotes exports from country i to country j in year t, $time_{ijt}^{\text{Steam}}$ denotes the transport time from i to j using a steamship, and $time_{ijt}^{\text{Sail}}$ denotes the transport time using a sailing ship. β_t^{Steam} and β_t^{Sail} are the coefficients. Since a longer transport time reduces trade, β_t^{Steam} and β_t^{Sail} are expected to be negative. Pascali (2017) shows that, over the sample period, the absolute value of β_t^{Sail} decreased while the absolute value of β_t^{Steam} increased. It indicates that steamships' travel time became more important in explaining trade volumes than sailing ships' travel time after 1860.

The second step is to obtain predicted trade values:

$$\ln(\widehat{EX}_{it}) = \sum_{j \neq i} w_j \left\{ \widehat{\beta}_t^{\text{Steam}} \ln\left(time_{ijt}^{\text{Steam}}\right) + \widehat{\beta}_t^{\text{Sail}} \ln\left(time_{ijt}^{\text{Sail}}\right) \right\},$$

where w_j denotes the share of country j in global trade. The third step is to estimate the following regression

$$\ln(GDPpc_{it}) = \beta_0 + \beta_1 \ln\left(\frac{EX_{it}}{GDP_{it}}\right) + \theta_i + \theta_t + u_{it},$$

by instrumenting $\ln\left(\frac{EX_{it}}{GDP_{it}}\right)$ using $\widehat{\ln(EX_{it})}$. It is estimated using the population size as of 1860 as weights.

There are two differences between Feyrer's method and Pascali's method. First, while Feyrer uses log of trade (the sum of exports and imports) as the explanatory variable, Pascali uses log of the export-to-GDP ratio. Second, while Feyrer uses $\ln(\widehat{T}_{it})$ as an instrument for $\ln(T_{it})$, Pascali uses $\widehat{\ln(EX_{it})}$ as an instrument (note the difference in the range of the "hat", while the former is $\widehat{\ln(A)}$ the latter is $\ln(\widehat{A})$).[51]

Table 7 summarizes Pascali (2017)'s results, illustrating that the impact of exports on income levels is negative for both OLS and IV estimates. The IV results show that a one percentage point increase in the export-to-GDP ratio decreases GDP per capita by 2%. Pascali (2017) notes that it was the first, to his knowledge, to show a negative "causal" effect of trade on income.[52]

[51] According to Jensen's inequality, for a random variable A, the following relationship holds: $\ln\left(E[A]\right) \geq E[\ln(A)]$. Therefore, the two approaches lead to different values.

[52] Some studies have demonstrated a negative "correlation" between globalization in the late 19th century and income levels. For example, see pp.2847–2848 of Pascali (2017). Using data from the 19th century onward, Clemens and Williamson

Table 7: Pascali's (2017) results, with $\ln(GDPpc)$ as the dependent variable

	OLS (1)	IV (2)
$\ln(Exports/GDP)$	-0.054	-0.200
	(0.031)	(0.087)
Sample size	344	344
Number of countries	37	37
First-stage F-stat.		26.5

Note: This table comes from columns (1) and (2) of Table 6 in Pascali (2017), estimated using data from 1845 to 1905 at five-year intervals, covering 13 periods. Standard errors are in parentheses. The regressions include control variables and fixed effects, but these are not reported in the table.

5.3 A study using the Baltic Dry Index as an instrumental variable

Lin and Sim (2013) use the Baltic Dry Index, a shipping cost index, as an instrument for trade. The "Baltic" refers to bulk, and "dry" denotes dry commodities, meaning the index tracks shipping costs for transporting non-liquid primary goods such as grain, coal, and iron. They introduce a theory that the "income elasticity of demand for primary goods" is lower than that for industrial goods, implying that trade benefits developed countries more than developing countries. Using data from 48 developing countries, they test the validity of this theory.

Lin and Sim (2013) highlight three advantages of using the Baltic Dry Index as an instrument when estimating the effect of trade in developing countries. First, using the Baltic Dry Index allows for broader country coverage than Feyrer (2021), which relies on the closure of the Suez Canal from 1967 to 1975 as a natural experiment and is therefore limited because many developing countries lack data for the 1960s and 1970s. Second, using the Baltic Dry Index allows for variation from developing countries, unlike Feyrer (2019), where air transport mainly captures exogenous variation in developed countries because its effect in developing countries is smaller. Third, because developing countries primarily export primary goods, fluctuations in the Baltic Dry Index effectively capture exogenous variation in their trade.

The regression equation is as follows:

$$\ln(GDPpc_{it}) = \beta_0 + \beta_1 \ln(T_{it}) + \theta_i + \theta_t + u_{it},$$

where T_{it} denotes country i's trade in year t,[53] and to address the endogeneity of $\ln(T_{it})$, the following is used as an instrumental variable:

$$IV_{it} = s_{it-1} \ln(BDI_t).$$

Table 8 summarizes Lin and Sim (2013)'s results. Both the OLS and IV estimates show a positive effect of trade on income levels and suggest that the OLS estimate is downwardly biased. The IV estimate is 0.534, which is close to the IV estimate of 0.459 obtained by Feyrer (2019) using air transport as an instrument. Based on these results, Lin and Sim (2013) conclude that trade increases income levels not only in developed countries but also in developing countries.

Table 9 summarizes results from existing studies that conduct causal inference on the effect of trade on income levels. It summarizes that one of the first serious causal analyses, Frankel and Romer (1999), prompted numerous follow-up studies seeking to identify the causal effects of trade.

(2004) show that, before 1950, there was a positive correlation between tariff rates and income growth rates, and Vamvakidis (2002) found a negative correlation between openness and income growth rates. One potential reason is that, before 1950, many countries pursued protectionist policies, which made it difficult for open economies to achieve growth through free trade.

[53] Although not specified in the paper, it is believed to be the sum of exports and imports.

TABLE 8: Lin and Sim's (2018) results, with ln($GDPpc$) as the dependent variables

	OLS (1)	IV (2)
ln(Trade volume)	0.331	0.534
	(0.116)	(0.186)
Sample size	760	712
Number of countries	48	48
First-stage F-stat.		59

Note: This table comes from Table 2's column IV and Table 4's column I of Lin and Sim (2013), estimated using annual data from 1955 to 2010, covering 16 periods. Standard errors are in parentheses. The regressions include control variables and fixed effects, but these are not reported in the table.

TABLE 9: Summary of the results in the existing studies

Study	Explanatory variable	N_T	N_C	Instrumental variable	OLS	IV
Frankel and Romer (1999)	(Exports + Imports)/GDP	1985	150	Geographic determinants	0.85	1.97
Felbermayr and Gröschl (2013)	(Exports + Imports)/GDP	1950–2008	162	Foreign natural disasters	0.40	1.76
Feyrer (2019)	ln(Exports + Imports)	1950–1995	101	Emergence of air transportation	0.45	0.46
Feyrer (2021)	ln(Exports + Imports)	1960–1984	80	Opening of the Suez Canal	0.30	0.23
Pascali (2017)	ln(Exports/GDP)	1845–1905	37	Emergence of steamships	-0.05	-0.20
Lin and Sim (2013)	ln(Trade)	1955–2010	48	Baltic Dry Index	0.33	0.53

Note: N_T indicates the sample period. N_C indicates the sample countries. The dependent variable is the natural log of GDP per capita in all the papers listed in Table 9. In the case of Lin and Sim (2013), the term "trade value" likely refers to "exports + imports," but since this is not explicitly stated, it is referred to as "Trade."

6 Other studies

6.1 The fall of the Berlin Wall as an instrument

This section discusses two additional studies that employ the IV approach.[54] Buch and Toubal (2009) apply Frankel and Romer (1999)'s approach to data from 16 states of Germany over the 1991–2004 period. Among these 16 states, those that were part of East Germany continued to experience lower openness, even after the fall of the Berlin Wall in 1989, which is called the "long shadow" effect.

Buch and Toubal (2009) closely follow Frankel and Romer (1999), with the introduction of interaction terms between the East Germany dummy and year dummies in the first-stage to utilize the "East Germany effect" as an exogenous shock. The results show that a one percentage point increase in openness increased income per capita by 0.0012%.[55]

6.2 The historical context of trade liberalization in the 1980s and 1990s as instruments

Studies discussed so far measure "openness" using trade values (exports + imports). However, Estevadeordal and Taylor (2013) argue that trade is determined by the government's trade policy, such as tariffs and import quotas, making it endogenous.[56] Accordingly, they use tariff rates, a variable directly controlled by the government, as the key explanatory variable.

Moreover, Estevadeordal and Taylor (2013) separately introduce the average tariff rates on consumer, capital, and intermediate goods instead of using the average tariff rate across all goods. They show that tariff cuts on capital and intermediate goods—factors that can theoretically boost income—have a larger

[54]The estimates in the studies discussed in Section 6 are not directly comparable to those in Section 5. Buch and Toubal (2009)'s estimates differ greatly from those in Section 5, possibly because Buch and Toubal (2009) uses data from German states rather than country-level data. Similarly, Estevadeordal and Taylor (2013)'s estimates cannot be compared to those in Section 5 because both the dependent and independent variables differ.

[55]See Column S8 of Table 5 of Buch and Toubal (2009).

[56]Therefore, endogeneity must be appropriately addressed, as in Frankel and Romer (1999), Felbermayr and Gröschl (2013), Feyrer (2019), and Feyrer (2021).

positive effect on income levels than tariff cuts on consumer goods. Estevadeordal and Taylor (2013) also note that earlier studies, such as Dollar (1992) and Sachs and Warner (1995), use data only from before 1990. To incorporate the trade liberalization episodes of the 1990s and beyond, they extend the sample period to 1975–2004.

Estevadeordal and Taylor (2013) estimate the following equation:

$$\Delta g_i = \beta_0 + \beta_1 \Delta \ln(1+\tau_i) + \Delta \mathbf{X}_i' \boldsymbol{\beta}_2 + u_i,$$

by using first-difference variables for the two periods, 1975–1989 and 1990–2004.[57] The variable g_i denotes the difference in the annualized average growth rate of GDP per person for country i between the two periods, and $\Delta \ln(1+\tau_i)$ denotes the rate of change in tariff rates between the two periods. $\Delta \mathbf{X}_i$ denotes a vector that includes lagged dependent variables, changes in average years of education, and changes in indices measuring social institutions. Since this is a first-difference estimation, country fixed effects are taken into consideration.[58]

To address potential endogeneity of tariff rates, Estevadeordal and Taylor (2013) exploit the historical context of trade liberalization to construct their instruments. They argue that many countries that liberalized trade had joined the General Agreement on Tariffs and Trade (GATT) in 1975 and subsequently reduced tariffs during the Uruguay Round negotiations from 1986 to 1994. Therefore, GATT membership in 1975 can be viewed as a precursor to trade liberalization and used as an instrument.

Estevadeordal and Taylor (2013) go further back to explore the historical differences in economic policies across countries, tracing them back to the Great Depression of the 1930s. Their hypothesis, in broad terms, is that "countries that suffered significant losses during the Great Depression became skeptical of the capitalist system and, as a result, maintained high tariffs in the post-1945 period. These countries were less likely to embrace the wave of trade liberalization during the 1980s and 1990s."

In particular, they construct the two instruments for $\Delta \ln(1+\tau_i)$ as follows:

$$IV_i^a = \ln\big(1+\tau_{1985,i}\big) \times D_{1975,i}^{\text{GATT}},$$
$$IV_i^b = \ln\big(1+\tau_{1985,i}\big) \times \big\{\ln\big(GDP_{1930\text{–}35,i}\big) - \ln\big(GDP_{1929,i}\big)\big\}.$$

The first variable, IV_i^a, is the tariff level in 1985 multiplied by a dummy taking unity if the country had joined the GATT in 1975. The second variable, IV_i^b, is the 1985 tariff level multiplied by a measure of the extent to which the average GDP of 1930–1935 deviates from that in 1929. Both instruments are expected to have negative coefficients, as higher values are predicted to lead to greater tariff reductions.

Table 10 summarizes results. The OLS estimates shown in column (1) indicate a 1% reduction in tariff rates increases GDP per capita growth rates by 0.03 percentage points. Columns (2) and (3) present the results from the IV method. In the first stage, the instruments show the expected signs and are statistically significant. The second-stage estimates exceed the OLS estimates, indicating that the OLS estimates are downwardly biased. Given that the median country's average tariff cuts is 25%, Estevadeordal and Taylor (2013) demonstrate that the effect on GDP per capita growth by multiplying the coefficient by 25 (also shown in Table 10). It suggests that a 25% reduction in tariffs increases the

[57] Estevadeordal and Taylor (2013) mention that the reason for using a first-difference estimation over two long periods, rather than annual data, is to remove the effects of short-term fluctuations in GDP caused by policy changes, business cycles, and financial crises. See the second paragraph of the left column on page 1678 in Estevadeordal and Taylor (2013).

[58] However, there is a potential criticism from Rodrik et al. (2004) that a reduction in tariff rates and other changes in trade policies might merely serve as proxies for "improvements in the quality of social institutions." This implies that the estimated effects may reflect the impact of improved social institutions rather than trade liberalization itself. To address this criticism, Estevadeordal and Taylor (2013) conduct additional analysis, regressing $\Delta \ln(1+i)$ on variables measuring the quality of social institutions. They find that countries that improved the quality of their social institutions experienced smaller reductions in tariff rates, thereby mitigating the concern raised by Rodrik et al. (2004).

GDP per capita growth rate by 0.83 to 1.27 percentage points.[59] Although this number might seem small, over a 15–20 year span, it results in a growth of 15% to 20%, which is a large effect, especially for developing countries.[60]

Table 10: Estevadeordal and Taylor (2013)'s results, with Δg as the dependent variable

	OLS (1)	IV (2)	IV (3)
$\Delta \ln(1+\tau)$	-0.0333	-0.0482	-0.0507
	(0.016)	(0.021)	(0.022)
Sample size	44	44	44
Effect of 25% tariff reduction	0.83 pp	1.21 pp	1.27 pp
Result of the first-stage, the dependent variable is $\Delta \ln(1+\tau)$			
IV^a		-0.517	
		(0.072)	
IV^b			-0.650
			(0.025)

Note: This table's column (1) comes from Table 3's column (5) in Estevadeordal and Taylor (2013). This table's columns (2) and (3) come from Table 7 of Estevadeordal and Taylor (2013). τ denotes the tariff rate on capital goods and intermediate goods in all columns. Standard errors are in parentheses. The dependent variable is the change in annualized per capita GDP growth rate over the two periods.

7 Conclusions

This paper reviews studies on the effects of international trade on income, focusing on the evolution of estimation methods. Early research often relied on small samples, ad hoc openness measures, and limited treatment of endogeneity. Nevertheless, these pioneering studies initiated the field despite severe data and methodological constraints, while critical reassessments and methodological innovations by subsequent scholars were essential for its advancement. Importantly, such critiques arose not because the early work was merely preliminary, but because it was influential. More broadly, ongoing critical debate and the development of more reliable estimation methods have played central roles in advancing the field.

Academic studies are intended to advance existing knowledge by building on prior research. Although we live in an era of abundant downloadable data, powerful computing resources, and sophisticated statistical software, producing well-recognized work remains challenging because it requires a deep understanding of the literature. In applied empirical research, scholars must read prior studies critically and design identification strategies that yield credible results. This demands not only mathematical and statistical skills but also an understanding of historical and institutional contexts that can serve as natural experiments, as well as a strong commitment to research. Additionally, one defining feature of top-journal publications is the originality of their datasets. Thus, it is increasingly important not only to extract new insights from existing data but also to contribute by constructing new datasets.

As for the question, "Does international trade increase income?" it seems that, with respect to the latter half of the 20th century, the answer is "Yes." What would the future research agenda be? I believe that the key areas for future exploration include identifying the pathways through which international trade raises income levels and understanding the heterogeneity in the effects of trade—particularly how it impacts different consumers and producers within a country. This type of analysis has already been extensively conducted not as studies using country-level panel data but rather as research that derives estimates by fitting theoretical models to data from specific countries or using microdata from particular

[59] However, Estevadeordal and Taylor (2013) emphasize that the estimated increase in the annual GDP per capita growth rate due to a 25% reduction in tariffs is between 0.75 and 1 percentage points. See the second paragraph on the right side of page 1681.

[60] See the third paragraph of Section 7 on pages 1688 and 1689.

nations.[61] However, such studies often face the challenge of external validity. In the future, there may be a growing demand for research that bridges the gap between studies using macro-level panel data, which provide some degree of external validity, and those using micro-level data, which offer greater statistical power and a more reliable estimation approach but lack such external validity.

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[61] For examples, see Feenstra (2018) and Borusyak and Jaravel (2021), respectively.

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