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The Green Revolution, grain imports, and income divergence in the developing world[☆]

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ABSTRACT

This study finds that the Green Revolution (GR), initiated in the 1960s, substantially increased grain imports and reduced economic growth in developing countries with below-average adoption of GR technologies. Using the exogenous timing of the GR across crops cultivated in different countries, this study estimates that, for an average developing country with an adoption rate of GR crops below the developing world average, the GR that occurred in other countries more than tripled its grain imports. This, in turn, reduced the GDP per capita by approximately one-third in low-adopting countries between 1965 and 2000. The substantial damage can be mostly explained by the resulting lower agricultural outputs, higher fertility, and lower human capital investment. This study suggests that increasing agricultural productivity is the most pertinent way to accelerate the stagnant growth historically experienced by developing countries damaged by the GR.

1. Introduction

The two major phases of income divergence in modern history coincide with two agricultural revolutions, both in timing and region. As shown in Fig. 1, Western countries began to diverge gradually from the rest of the world around the early 19th century, closely following the British Agricultural Revolution that started in 18th century England and then spread first to Europe and Western offshoots (Overton, 1996; Allen, 2011). The figure classifies countries that have lagged behind since the first income divergence into two groups based on their 2000 adoption rate of high-yielding crop varieties (HYVs), which have characterized the Green Revolution (GR) in the developing world since the mid-1960s (Pingali, 2012). It shows that after sharing virtually identical growth trends for centuries, countries with high HYV adoption diverged from the rest of the developing world following the GR.[1] This coincidence naturally leads to the conjecture that agricultural revolutions are a major cause of global income divergence.

This study aims to quantify the impact of the GR on the second income divergence. While many studies have established a positive causal link between agricultural growth and economic development, it remains unclear to what extent the agricultural revolution can explain the historical income divergence. Quantifying the impact of the British Agricultural Revolution on the first income divergence has proven challenging because both events occurred gradually and lasted for centuries (Mokyr, 2011; Jones, 2016). However, the sharp GR in the developing world since the mid-1960s, largely driven by exogenous technology transfer from the

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[☆] This paper is a substantially revised version of earlier working papers with the title of Agricultural Productivity and Income Divergence: Evidence from the Green Revolution. I am grateful for the useful comments and suggestions from Douglas Gollin.

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[1] The first income divergence is usually referred to as the Great Divergence or European Miracle (Jones, 1981; Pomeranz, 2000), while the second income divergence is usually seen as the "conditional convergence" between the developing and developed worlds (Ben-David, 1993; Barro and Sala-i Martin, 2004; Acemoglu, 2009).

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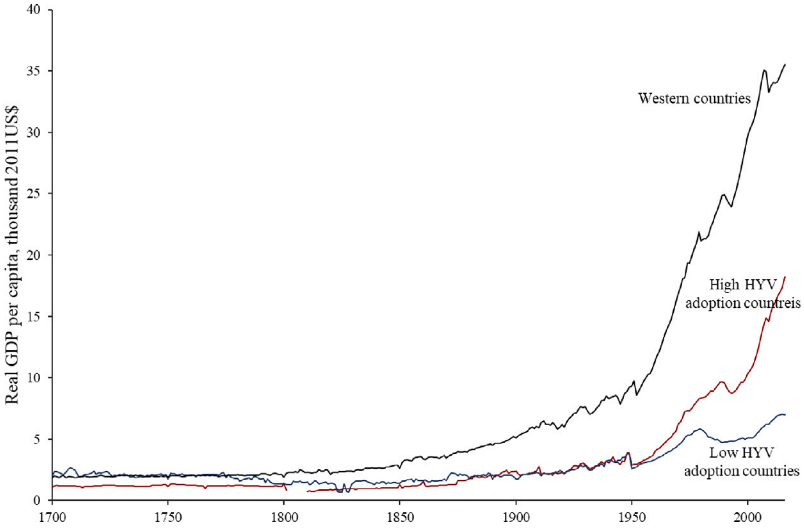

Fig. 1. Two phases of income divergence in modern history.
Notes: This figure classifies 134 countries with a population of more than 1 million in 1960 into three groups: 30 developed countries from the Western world (including most European countries, Western offshoots, and Japan; excluding Eastern European and South American countries), 66 developing countries in which the adoption rate of high-yielding crop varieties (HYVs) in 2000 was below the developing world average (i.e., the low HYV adoption countries; see Section 4.2 for details), and the remaining 38 developing countries (i.e., the high HYV adoption countries). The data on GDP per capita (in thousand 2011US$) are derived from the Maddison Project Database 2018.

developed world (Hazell, 2009; Conway, 2012), provides an excellent opportunity to identify the causal effect of the agricultural revolution. Using long-term panel data obtained from the GR, this paper attempts to answer the following questions: To what extent can the GR explain the second income divergence? What are the mechanisms behind this effect? Has the growth of countries benefited more from the GR adversely affecting the growth of countries that gained less agricultural productivity from the GR?

There are two critical facts that are essential to understanding the impact of the GR on cross-country income divergence. First, the agricultural productivity gained from the GR varied significantly across developing countries with different suitability for cultivating GR crops (i.e., HYVs) (Evenson, 2005). Second, developing countries less suitable for cultivating HYVs experienced dramatic increases in grain imports following the GR (see Fig. 5). These facts imply two channels for the GR to affect domestic economic growth: a direct effect through domestic HYV adoption and an indirect effect through international grain trade. While the direct effect of the GR on national income has been rigorously estimated by Gollin et al. (2021), who demonstrated that developing countries that adopted more HYVs experienced faster economic growth, the indirect effect of the GR through grain trade has not yet been examined to the best of my knowledge. The main contribution of this study is thus to estimate the indirect effect of the GR through grain trade and then combine it with the direct effect to evaluate the GR's total effect on cross-country income divergence.

To estimate the indirect effect of the GR, I undertake two steps. Firstly, I estimate the effect of the GR on grain trade, and secondly, I estimate the effect of GR-caused grain trade on income per capita. The estimations are based on 75 developing countries, which account for about 90% of the developing world population, and for which data on the adoption rate of HYVs and grain trade are available. Using the HYV adoption rate data, I construct a measure of the GR's differential effect on grain productivity across countries, called the relative disadvantage in adopting HYVs (RDA). RDA is calculated as the developing world harvesting-area-weighted average adoption rate of HYVs minus the individual-country HYV adoption rate.[2] A country with a higher RDA is more disadvantaged during the GR. Since several large countries such as India and China have much higher HYV adoption rates than other countries, 63 of the 75 developing countries were disadvantaged during the GR (i.e., with a positive RDA). I estimate the effect of the GR on grain trade by regressing the log net grain imports on RDA in a fixed-effects panel model. The regression addresses the endogeneity of RDA by using instrumental variables (IVs) constructed based on each country's agro-climatic suitability for cultivating HYVs and from the exogenous timing of the staggered release of HYVs across crops. The estimation shows that a 1% increase in RDA leads to 8 percentage point higher grain imports and that the GR more than tripled the grain imports in an average GR-disadvantaged country from 1965 to 2000.

Next, I estimate the effect of grain imports on income by regressing the log GDP per capita on the log net grain imports in a fixed-effects panel model. To address the endogeneity of grain imports and to identify the impact only from the GR, I construct a Bartik IV based on the GR-caused supply shocks from net grain-exporting countries and the bilateral distance of each developing country to these grain exporters. I show that the Bartik IV affects domestic economic growth only after the GR. Note that I do not

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[2] I will illustrate that while this measure facilitates understanding the estimated effect, a similar result can be obtained when simply using the country-level HYV adoption rate as the explanatory variable in a panel model with the year fixed effects.

use the IVs constructed for RDA because they are necessarily correlated with domestic HYV adoption, and, thus, affect domestic income not only through grain imports. The IV estimates suggest that a 1 percentage point increase in net grain imports reduced GDP per capita by 0.12 percentage points. For an average GR-disadvantaged country, the GR-caused grain imports reduced the GDP per capita by about one-third by 2000. The estimated effect is robust to using alternative IVs, adopting different measures of grain imports, and extending the sample to more countries. A mediation analysis shows that the detrimental effect of the GR-caused grain imports can mostly be explained by the resulting faster population growth, slower human capital formation, and lower agricultural and manufacturing outputs.

Finally, I evaluate the explanatory power of the GR on income divergence by combining its indirect effect through grain imports with its direct effect through domestic HYV adoption. The direct effect is estimated by regressing log GDP per capita on domestic HYV adoption rates, closely following Gollin et al. (2021). The sum of the estimated indirect and direct effects indicates that 37 of the 75 developing countries benefited from the GR, while the remaining 38 were damaged. Countries that experienced the largest loss were from Africa, while the ones that gained the most were from Asia. The average gain of the benefited countries was 35.3% of 2000 GDP per capita, while the average loss of the damaged countries was 31.4%. A counterfactual analysis shows that removing the GR's total effect can largely eliminate the income divergence observed between these two groups of developing countries since the 1960s. Therefore, without the GR, Asian developing countries could have experienced no faster growth, on average, than African countries.

I would like to highlight the difference between the findings of this study and those of Gollin et al. (2021). Both studies identified a positive link between the adoption rate of HYVs and economic growth, but the targets of the study and the implications of the estimates are fundamentally different. This study focuses on examining the effect of GR-caused grain imports, while their study focuses on examining the effect of domestic GR on domestic economic outcomes. To exclude the confounding effect of domestic HYV adoption, this study constructs a Bartik IV for grain imports based on foreign grain supply shocks that are exogenous to the HYV adoption of individual developing countries. In contrast, their empirical strategy focuses on estimating the effect of domestic HYV adoption on domestic economic outcomes. Therefore, the positive link in this study is driven by the damage of GR-caused grain imports, while the positive link in their study is driven by the benefits of domestic HYV adoption. This difference is most clear when focusing on countries that adopted no HYVs; these countries are most seriously damaged according to my estimate but are unaffected according to their estimate. I also present the country-level differences in the estimated effects based on these two studies (Panels A and B in Fig. 11).

This article complements the large body of literature examining the causal effect of agricultural growth on economic development (Nunn and Qian, 2011; Kopsidis and Wolf, 2012; Gollin et al., 2014; Andersen et al., 2016; Dall Schmidt et al., 2018; Carillo, 2021; Adamopoulos and Restuccia, 2021). More relevantly, some of these studies examined the causal effect of agricultural growth from the GR (Foster and Rosenzweig, 1995; Evenson and Gollin, 2003b; Foster and Rosenzweig, 2004; Moscona, 2019; Gollin et al., 2021). These studies focus on examining the causal effect of domestic agricultural productivity on domestic economic outcomes and generally find that countries (regions) that have experienced more agricultural growth have better subsequent economic performances. Consistent with this literature, this article also establishes a positive cross-country causal link between agricultural growth and economic growth. But the underlying mechanism of the positive link highlighted in this article is that countries that gained more agricultural productivity from the GR negatively impact the economic growth of foreign countries through international grain trade. This finding is consistent with the common belief in the agricultural economics literature that new agricultural technologies lead to lower agricultural product prices, causing non-adopters of these technologies to lose. However, to the best of my knowledge, this study is the first to seriously explore the positive causal link between agricultural growth and economic growth through the channel of grain trade.

This article contributes to the macro literature that attempts to explain cross-country income divergence. For example, Mokyr (2001) argued that institutions facilitating the protection of property rights have been the primary driver of income divergence, Pomeranz (2000) emphasized the effect of geographical factors, and Galor and Mountford (2006) highlighted the role of human capital. Complementing these studies, this article shows that the differential agricultural productivity growth across countries is also a major cause of income divergence. This article is closely related to studies showing that trade enlarged income divergence by affecting specialization (Krugman and Venables, 1995), learning by doing (Young, 1991), and fertility and education (Galor and Mountford, 2008). However, this article attempts to identify a causal link by focusing on the effect of plausibly exogenous grain trade caused by the GR.

This article also contributes to answering the question that is central to the development policies of most developing countries: is agricultural growth still necessary in a world with declining food prices? Although the conventional view is that agricultural development is necessary for long-term economic development,[3] there is a growing debate over whether the conventional wisdom still applies in a more integrated global environment with falling food prices (Hart, 1998; WorldBank, 2007). As food prices today are determined more by border prices, declining world food prices (see Fig. 3) might reduce the need to invest in agriculture. However, this study finds that grain imports substantially retard economic growth in most developing countries that fall behind in agriculture, especially those abundant in natural resources. Therefore, even in an integrated global environment,

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[3] This view has been formalized by recent theoretical studies (e.g., Gollin et al., 2002; Restuccia et al., 2008; Vollrath, 2011) and is supported by abundant empirical evidence (e.g., Foster and Rosenzweig, 1996; Bustos et al., 2016; Gollin et al., 2021).

domestic agricultural productivity growth is still necessary for most developing countries to successfully launch their economic transformations.[4] In this sense, the findings of this article lend support to agricultural protectionist interventions in developing countries that are disadvantaged in agriculture.

I conclude this article by clarifying the welfare implications of the findings. While per capita income is a primary determinant of welfare, it cannot capture all dimensions of human well-being. In Appendix Tables A.8, I further show that the GR-caused grain imports also deteriorate other welfare measures: per capita consumption, life expectancy, infant mortality, and poverty rate. Nevertheless, it is important to remember that a major driving force of these per capita welfare impacts is the resulting population expansion. As such, the welfare implication involves a deep philosophical question: How do we think about the welfare of people who are alive in one scenario but might not have ever been born in another scenario? In addition, a larger population may lead to faster economic growth in future generations, according to the scale-effect prediction of R&D-based growth theories (Romer, 1990; Jones, 1995; Howitt, 1999). Therefore, the welfare implication of the GR for GR-disadvantaged countries depends on how we evaluate the welfare of the population expansion and how it contributes to future economic growth.

2. Key facts about the GR

This section present five key facts that are critical for understanding the impact of the GR and for the identification strategy of this study.

2.1. The GR was largely exogenous to individual developing countries

The GR was exogenous because its timing was determined by international institutions, and its intensity was determined largely by the local agro-climatic suitability of major GR crops. The GR was a set of technology transfer initiatives that increased agricultural productivity in the developing world, beginning, most markedly, in the mid-1960s (Hazell, 2009). International institutions, most importantly, the Consultative Group on International Agricultural Research (CGIAR), played a critical role in the GR. The crop productivity growth in the developing world was largely driven by crop germplasm improvements in CGIAR centers, which were then transferred to national agricultural programs for adaptation and dissemination (Conway, 2012). The GR's success was based on scientific advances already made in the developed world for three major staple crops: rice, wheat, and maize (Hazell, 2010). Meanwhile, the CGIAR research programs focused on other major crops, such as cassava, sorghum, and millets, were introduced much later (Renkow and Byerlee, 2010). Therefore, countries with agro-climatic conditions more suitable for cultivating the three major GR crops gained more agricultural productivity from the GR (Evenson and Gollin, 2003b). These facts imply that the timing and intensity of the GR could be used to identify its causal effect.

2.2. Productivity gains from the GR differed substantially across developing countries

Productivity gains from the GR widely differed across countries with different HYV adoption rates. As presented in Fig. 2, for a sample of 75 developing countries, the average yield of the top 11 major food crops (for which the data on the HYV adoption rates are available) increased by 0.93 tons per hectare from 1965 to 2000, which equals a 72% increase compared to the average yield of 1965.[5] Productivity gains, however, were substantially different across countries. For example, the per hectare output increased by 1.9 tons in the 10 developing countries with the highest HYV adoption rates but only increased by 0.4 tons in the 10 developing countries with the lowest HYV adoption rates. A simple regression indicates that a 10% increase in the HYV adoption rate leads to a 0.15-ton higher per hectare output. Thus, it is plausible that the GR had different effects on economic performances across countries.

2.3. World grain prices have declined remarkably since the GR

Evenson and Gollin (2003b) estimated that without the GR, world grain prices would have been 35%–66% higher in 2000. Fig. 3 shows that the average price index for the three GR crops (rice, wheat, and maize) dramatically declined from 38.5 in 1960 to 16.7 in 2000. This decline was not driven by low food demand because the world population doubled from 3.0 billion to 6.1 billion during this period. In addition, Appendix Table B1 shows that the domestic grain prices of developing countries are highly correlated with the world grain prices, even for relatively closed countries. These facts imply that changes in food prices could be an important channel for the GR to impact domestic economic outcomes.

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[4] As will be shown in Section A, agricultural growth is not necessary when a developing country has a comparative advantage in manufacturing. However, Fig. 6 shows that most developing countries have no comparative advantage in manufacturing.

[5] To make the yields of the 11 crops comparable, I calculate their rice equivalents based on the calorie content. For example, 1 ton of potatoes has 763,353 calories, the same number of calories that are in 0.221 tons of rice, because rice has 3439,348 calories per ton. As such, one ton of potatoes expressed in rice equivalents is 0.221 tons. The calorie content information was obtained from the nutritional composition table provided by the United Nation World Food Program.

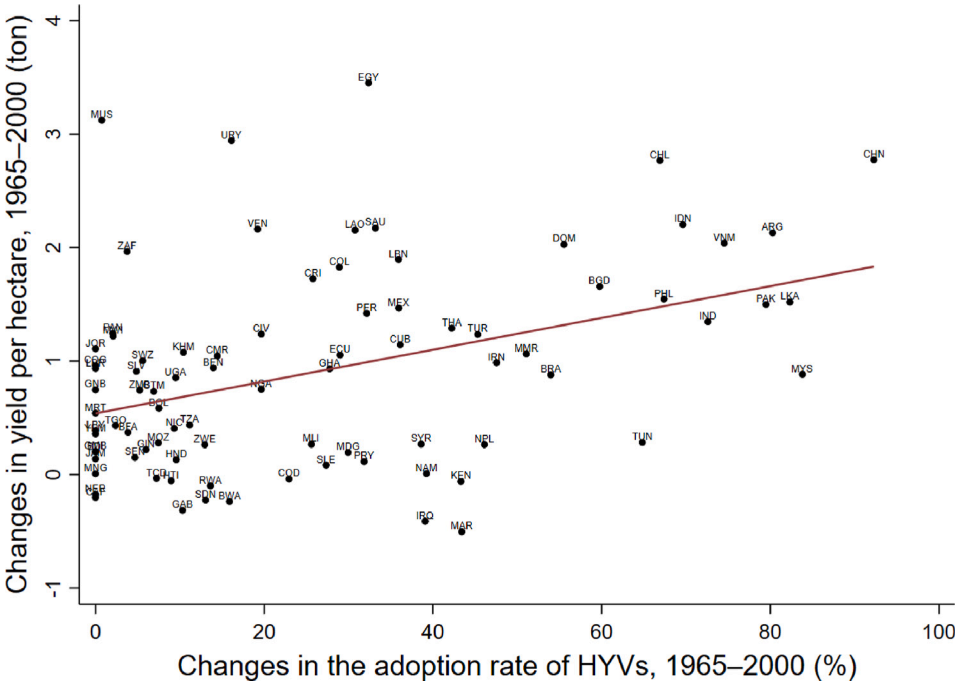

Fig. 2. Correlation between changes in crop yields and the adoption rate of HYVs from 1965 to 2000.

Notes: The country-level adoption rate of HYVs was calculated as the weighted average across the 11 major food crops (for which the data on the HYV adoption rates are available), using each crop's harvesting area as the weighting. The 11 major crops are wheat, rice, maize, barley, potatoes, millet, sorghum, cassava, dry beans, groundnut, and lentils. The yield per hectare is calculated as the rice equivalent (harvesting-area-weighted) average yield of the 11 crops (see Footnote 2.2). The data for HYV adoption rate and yield are derived from Evenson and Gollin (2003b) and the FAO Statistical Database, respectively.

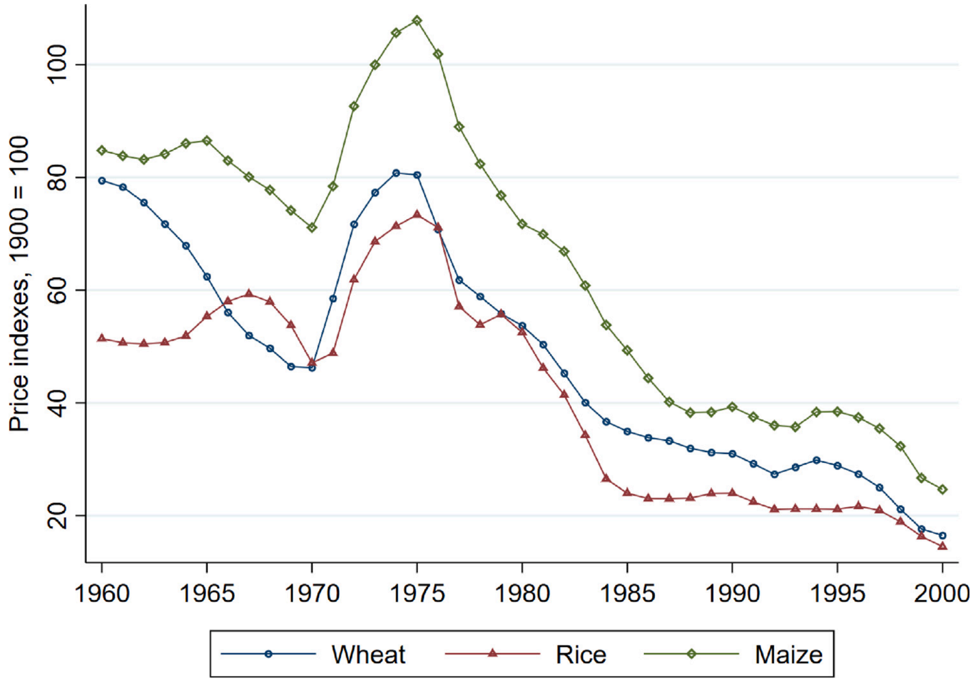

Fig. 3. Real prices of three major staple crops.

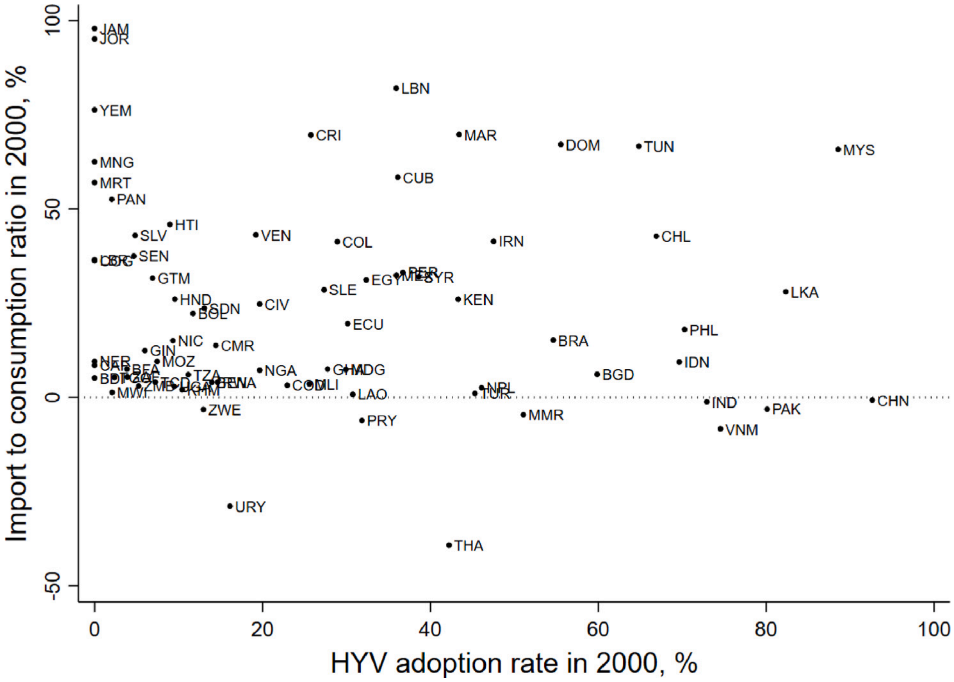

Fig. 4. Net import-to-consumption ratio of 11 major food crops in 2000.
Notes: The figure presents the net import-to-consumption ratio of the 11 major food crops among the 75 developing countries in 2000. The 11 crops accounted for about 96% of the total output of staple crops in the 75 countries, and the 75 countries accounted for about 90% of the developing world population. The 11 crops are aggregated based on their calorie contents. The data were derived from the FAO Statistical Database.

2.4. Grain imports have significantly increased in GR-disadvantaged countries

Somewhat counterintuitively, many developing countries depend heavily on grain imports for consumption (FAO, 2000; McCalla, 2001). Fig. 4 shows that among the 75 developing countries (accounting for about 90% of the developing world population) examined in this article, as many as 66 were net importers of the 11 major food crops in 2000 (the 11 crops accounted for about 96% of the total output of staple crops in these countries, calculated as the average during 1960–2000 based on FAO data). Among the 66 net importers, the net import–consumption ratio exceeded 10% in 51 and exceeded 50% in 13.

Fig. 5 presents the association between HYV adoption and changes in the import–consumption ratio from 1965 to 2000 for the 75 developing countries. For countries with an HYV adoption rate lower than the developing world average (i.e., disadvantaged countries), the average import–consumption ratio dramatically increased from 5.9% in 1965 to 26.9% in 2000. Similarly, for the one-third most disadvantaged countries, the ratio increased from 13.1% to 37.0%. In sharp contrast, for advantaged countries, the ratio declined from 13.2% to 4.9% over this period. This implies an important impact of the GR on grain trade.

2.5. GR-disadvantaged countries seldom have a comparative advantage in manufacturing

Fig. 6 shows that the comparative advantage of countries disadvantaged in adopting HYVs is generally in producing and exporting raw materials instead of manufactured goods. This is important for our analysis because, as detailed in the next section, the economic impact of the GR through grain trade depends on a country's comparative advantage. I measure the comparative advantage of a country using the revealed comparative advantage (RCA) based on Ricardian trade theory, according to which patterns of trade among countries are governed by their relative differences in productivity. Specifically, I follow the guidance of the United Nations Conference on Trade and Development (UNCTAD) to construct the RCA of each country based on annual international trade data derived from the World Development Indicators. A country is said to have a revealed comparative advantage in a given product when its ratio of exports of the product to its total exports of all goods exceeds the same ratio for the world as a whole. That is,

$$RCA_{Ai} = \frac{\frac{X_{Ai}}{\sum_{j\in P} X_{Aj}}}{\frac{X_{wi}}{\sum_{j\in P} X_{wj}}} \geq 1 \quad ,$$

where P is the set of all products (with $i, j \in P$), X_{Ai} is country A's exports of product i, and X_{wi} is the world's exports of product i.

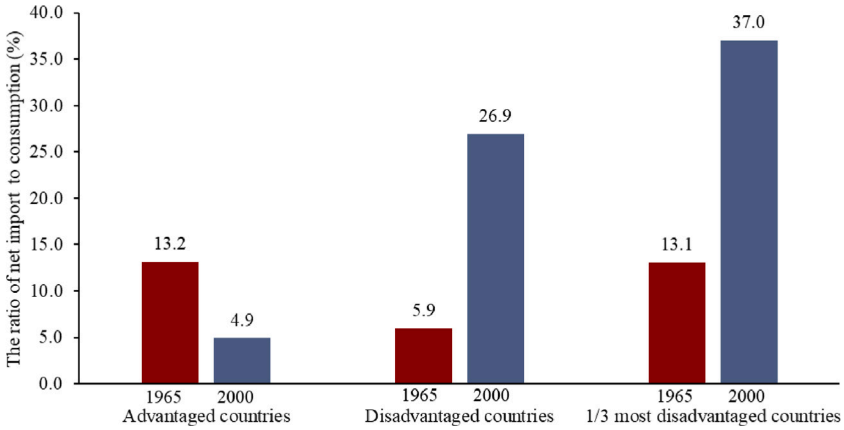

Fig. 5. Changes in the import–consumption ratio from 1965 to 2000.
Notes: The figure presents changes in the net import-to-consumption ratio of the 11 major food crops from 1965 and 2000 for the 75 developing countries. The ratio was calculated separately for the advantaged countries, disadvantaged countries, and 1/3 most disadvantaged countries. Advantaged (disadvantaged) countries are defined as those with an HYV adoption rate higher (lower) than the harvesting-area-weighted average adoption rate across the sample countries. The data were derived from the FAO Statistical Database.

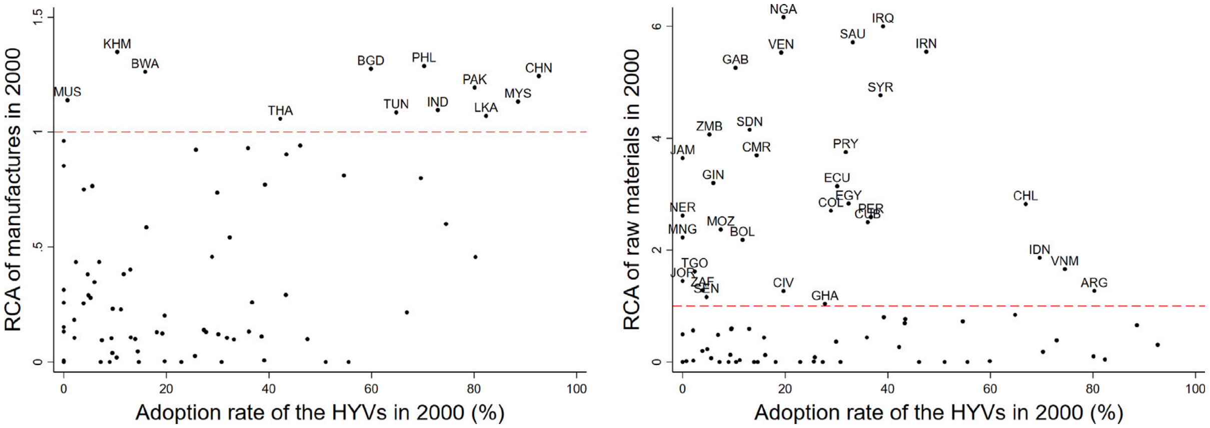

Fig. 6. Revealed comparative advantage (RCA) and the HYV adoption rates.
Notes: The left (right) graph presents the association between the RCA in manufactured goods (in raw materials) and the adoption rate of HYVs in 2000. The figure focuses on 75 developing countries for which the HYV adoption rate and trade data are available and with a 1960 population larger than 1 million.

I calculate the RCA for each of the 75 developing country based on the total export values of two groups of products: raw materials and manufactured goods. Here, raw materials include all products under the main categories of the standard international trade classification (SITC, version 3) of raw materials (Sections 2 and 4) and energy products (Section 3). Manufactured goods include all products under the SITC main categories of chemicals (Section 5), machinery and transport equipment (Section 7), and other manufactured goods (Sections 6 and 8). Fig. 6 shows that in 2000, most countries with a low adoption rate of HYVs have no comparative advantage in manufactured goods (left graph) but have strong comparative advantage in raw materials (right graph). The same RCA pattern is observed before the GR (in 1964), as presented in Appendix Figure A.1.

Note that here I present the association between RCA and HYV adoption rates only because the impact of the GR through grain trade depends on a country's comparative advantage. As detailed in the next section, only low-HYV adoption countries that have no comparative advantage in manufacturing will be damaged by the GR-caused grain imports. I highlight that the identification strategy of this article does not depend on any assumption about the causal link between RCA and HYV adoption rates. I depend on the exogenous timing of the GR across crops to identify the causal effects, and the timing of the GR should not be affected by the RCA of individual developing countries.

3. Conceptual framework

Standard trade theories suggest that a country tends to export those goods for which it has a comparative advantage and import those goods for which it has no comparative advantage (Ricardo, 1821). The GR increased the comparative advantage of agriculture for countries with high HYV adoption and reduced it for countries with low HYV adoption. As a result, net grain imports have significantly increased in GR-disadvantaged countries since the 1960s (Fig. 5). Existing studies suggest that the GR-caused grain imports can reduce domestic income by increasing population growth, retarding human capital formation, and reducing agricultural and manufacturing outputs.

Malthusian theory (Malthus, 1798) and the trade-off between quantity and quality of children (Becker and Lewis, 1973) imply that the GR-caused grain imports could reduce per capita income by increasing population growth and retarding human capital formation. Lower domestic grain prices due to the GR-caused grain imports (Fig. 3) could increase population growth by increasing fertility and reducing mortality (Malthus, 1798; Strulik and Weisdorf, 2008). Higher population growth mechanically reduces per capita income at least in the short run. Lower food prices also imply lower costs of raising children and higher relative costs of investment in the human capital of each child (Becker and Lewis, 1973; Becker et al., 1990). Utility-maximizing parents tend to make a trade-off between the quantity and quality of their children, and lower human capital investment could reduce the long-run economic performance of a country (Galor and Tsiddon, 1997).

Grain imports are also likely to reduce per capita income by damaging domestic agricultural production. Cheaper imported grains necessarily reduce domestic grain production and reduce the income of domestic net grain producers. In addition, the damage to agriculture could shift labor from agricultural to non-agricultural sectors and thus reduce wages in the latter, although the real income of net grain consumers in non-agricultural sectors may increase due to lower grain prices. Considering that agriculture accounts for substantial shares of economic output and employment in most developing countries, the impact of grain imports through domestic agricultural production could be large. This prediction is consistent with the common belief expressed in the agricultural economics literature that new agricultural technologies lead to lower agricultural product prices, causing losses among non-adopters of these technologies.

Grain imports may also reduce manufacturing growth in developing countries with no comparative advantage in manufacturing. To achieve a trade balance, GR-disadvantaged countries have to increase the exports of non-agricultural products. The nature of their exports depends on whether the country's comparative advantage lies in manufacturing or extractive industries (e.g., mining, oil, gas, and forestry). Matsuyama (1992) demonstrates that a disadvantage in agriculture could boost growth in countries with a comparative advantage in manufacturing (rather than in extractive industries) by leading them to specialize in manufacturing and to export more manufactured goods. However, Fig. 6 shows that most countries disadvantaged in terms of adopting HYVs have no comparative advantage in manufacturing but do have one in extractive industries. I show that developing countries which are disadvantaged in terms of adopting HYVs significantly increased their net imports of manufactured goods and net exports of raw materials (Columns 6 and 7 of Table 2). Therefore, labor and physical capital are shifted from agriculture and manufacturing to extractive industries to keep the trade balance. Lower domestic manufacturing production reduces the potential of growth because learning by doing in manufacturing is an important source of economic growth (e.g., Young, 1991; Grossman and Helpman, 1991). The loss may not be offset by the growth in extractive industries because the depletable nature of natural resources implies that productivity in extractive industries tends to decline with extraction.

Section 5.4 shows that most of the detrimental economic impact of the GR-caused grain imports can be explained by the resulting faster population growth, slower human capital formation, and lower agricultural and manufacturing outputs. In Online Appendix A, I also attempt to formalize these channels of impact by a simple theoretical three-sector model of open economies.

4. Effect of the GR on grain imports

4.1. Data

This article depends on data from the following seven sources: HYV adoption rate data from Evenson and Gollin (2003a); grain trade data from the FAO Statistical Database; GDP and population data from the Maddison Project Database; agro-climatic suitability for cultivating crops from the Global Agro-Ecological Zone dataset computed by FAO; release year of the first HYV for each crop compiled by Gollin et al. (2021); bilateral distances between countries from Mayer and Zignago (2011); and various control variables and trade of non-grain products from the World Development Indicators. These data sources and the variables constructed from them are detailed in Table A.2.

From these data sets, I construct a sample of 75 developing countries (listed in Table A.1) from 1960 to 2000 in five-year intervals.[6] This sample is chosen based primarily on the availability of the HYV adoption rate data from Evenson and Gollin (2003a), who compiled the HYV adoption rates for 91 developing countries from 1960 to 2000 in five-year intervals. From their sample countries, I exclude five for which the grain trade data are unavailable and 11 where the 1960 population was smaller than 1 million. The remaining 75 countries accounted for approximately 90% of the developing world population in 1960, calculated based on the Maddison Project Database. The developing countries missing from the sample are mainly the post-Soviet states, which accounted for approximately 8% of the developing world population. The study sample will be extended to continuous years from 1950 to 2016 and to 86 developing countries in various robustness checks.

I exclude all developed countries from the analysis for three reasons. First, while the GR is likely exogenous to developing countries, it is endogenous to traditionally developed countries because the GR's success was based on scientific advances that had already occurred in the developed world. Second, as the small group of developed countries (mainly the 38 OECD countries) could

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[6] Because the grain trade data from the FAO are not available before 1961, I use the grain trade in 1961 as an approximation of that in 1960.

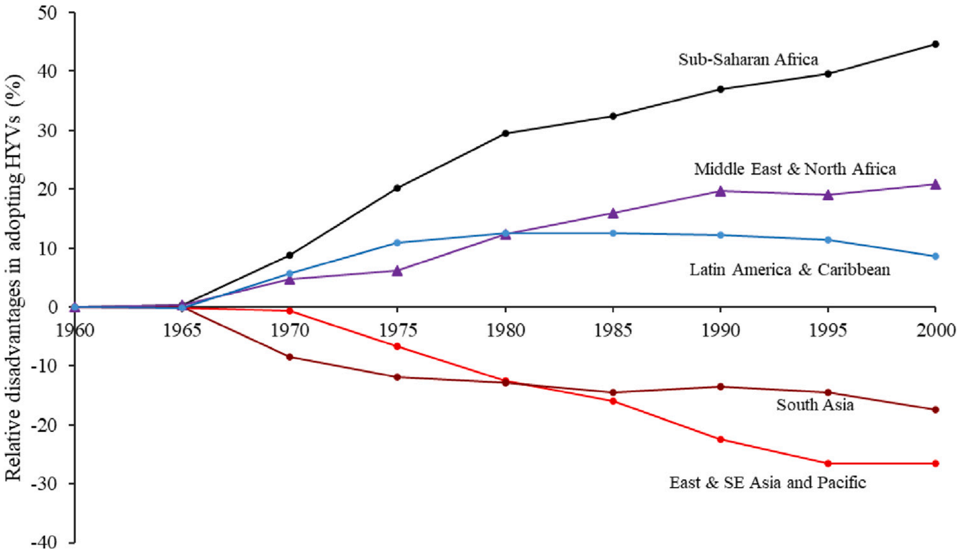

Fig. 7. Chronological and regional variations in the relative disadvantage in adopting HYVs (RDA).
Notes: RDA is constructed based on Eq. (1). The regional average RDA is calculated as the (harvested-area-weighted) average RDA for all sample countries within each region.

have different patterns of comparative advantage, the impact of grain trade on them is theoretically uncertain and empirically different to test. Finally, I believe that the impact of grain trade on most developed countries is likely to be negligible because agriculture generally accounts for a small share of GDP in these countries; for example, the share of agriculture in GDP was only 1.2% in the United States in 2000. In general, developed countries are just very different than the considered developing countries and including them weakens the overall empirical design.

4.2. Relative disadvantage during the GR

To measure the GR's relative effect across countries, I calculate the RDA of each country based on the HYV adoption rates of 11 major food crops (wheat, rice, maize, barley, potatoes, millet, sorghum, cassava, dry beans, lentils, and groundnut) compiled by Evenson and Gollin (2003a), which is the most complete data set on HYV adoption to the best of my knowledge. The HYV adoption rate of a crop is defined as the share of its harvested area planted with HYVs. The 11 crops accounted for about 96% of the total output of staple crops in the 75 sample countries (calculated as the average during 1960–2000, based on the FAO data).

The RDA of country i is constructed as the average HYV adoption rate of all other developing countries minus the HYV adoption rate of the country:

$$RDA_{it} = \overline{HYV}_{-it} - HYV_{it} \ , \tag{1}$$

where HYV_{it} indicates the harvested-area-weighted adoption rate of the 11 crops:

$$HYV_{it} = \frac{\sum_{j=1}^{J} HYV_{it}^{j} \times Area_{it}^{j}}{\sum_{j=1}^{J} Area_{it}^{j}},$$

where HYV_{it}^{j} is the share of the harvested area of crop j planted with HYVs in year t and country i, and $Area_{it}^{j}$ is the harvested area of crop j; $\overline{HYV}_{-it}$ is the weighted-average HYV adoption rate across the remaining 74 countries:

$$\overline{HYV}_{-it} = \frac{\sum_{z=1,z\neq i}^{Z} HYV_{zt} \times Totalarea_{zt}}{\sum_{z=1,z\neq i}^{Z} Totalarea_{zt}},$$

with the total harvested area of the 11 crops ($Totalarea_{it}$) as the weightings.

By construction, countries with a higher RDA are more disadvantaged in adopting HYVs. Fig. 7 presents the variation in RDA across regions and over time. It shows that the RDA was zero for all regions before 1965 but varied widely after that. The relative disadvantage across regions generally enlarged over time: East and SE Asia and the Pacific (red line) and South Asia (dark red line) became increasingly advantaged during the GR (i.e., with an increasingly negative RDA), while other regions became increasingly

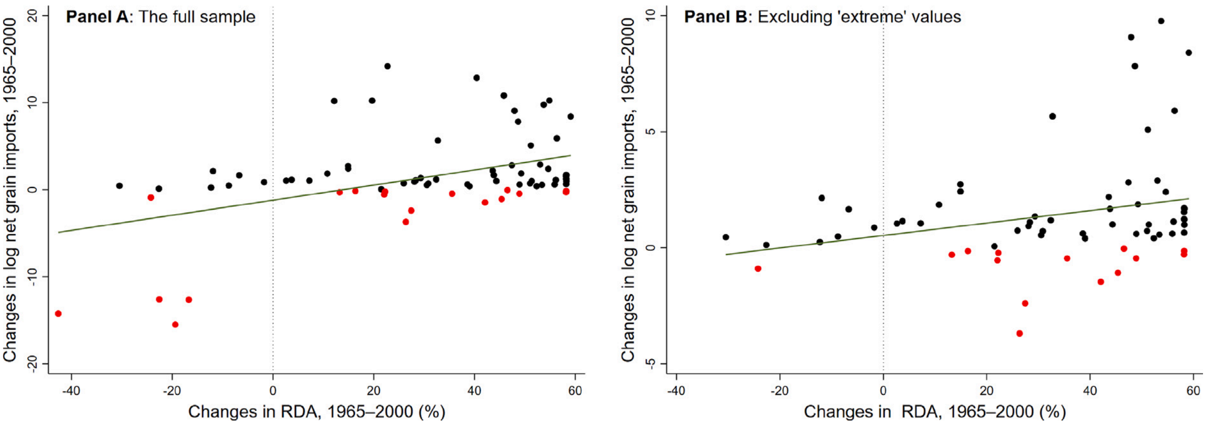

Fig. 8. Correlation between changes in log net grain imports and changes in RDA from 1965 to 2000.
Notes: Panel A includes all 75 sample countries, and Panel B excludes sample countries in which the changes in log net grain imports were higher than 10 or lower than −10. The red marks highlight the 18 countries that experienced a decline in net grain imports over this period. The net grain imports are the sum of the net import values (in 2011 US$) of the 11 major food crops.

disadvantaged (although the RDA in Latin America and the Caribbean declined slightly after 1980). The most disadvantaged region was Sub-Saharan Africa, where the RDA was as high as 46.9 in 2000.[7]

Panel A of Fig. 8 presents a positive correlation between changes in log net grain imports and changes in RDA from 1965 to 2000 for the 75 countries. A simple regression (without control variables) shows that a one-unit increase in RDA corresponds to an 8.5 percentage point increase in grain imports. Most countries that experienced a large increase in grain imports are GR-disadvantaged countries (i.e., with a positive RDA). For an average disadvantaged country, the log net grain imports increased by 2.5 from 1965 to 2000, which corresponds to more than an 11-fold increase in the net grain imports (i.e., $\exp(2.5) - 1 = 11.2$). Only 18 countries (marked by red) experienced a decline in the net grain imports over this period, and the countries that experienced the largest declines are the four large Asian countries that are most advantaged in adopting HYVs: China, India, Pakistan, and Vietnam. Panel B of Fig. 8 shows that the positive association remains when excluding countries in which the changes in log net grain imports were higher than 10 or lower than −10.

4.3. Estimation method

I estimate the effect of RDA on grain imports based on the following regression model:

$$\ln I_{it} = \upsilon_i + \tau_t + \alpha_1 RDA_{it} + Z_{it}\lambda + \varepsilon_{it} \quad , \tag{2}$$

where $\ln I_{it}$ is the natural log of net import values (in 2011 US$) of grains in country i and year t, calculated as the sum across the 11 major food crops. Z_{it} is a vector of control variables; υ_i and τ_t denote the country- and year-fixed effects, respectively; α_1 and λ are the coefficients; and ε_{it} is the error term. The estimation is mainly based on the five-year interval data from the 75 developing countries from 1960 to 2000. In robustness checks, I will also use the dependent variable of the log import-to-consumption ratio (column 2 of Table 2), extend the sample to 86 developing countries (column 5 of Table 2), and extend the sample period to continuous years from 1961 to 2016 (Panel A of Fig. 9). Note that the dependent variable in the main analysis is the total imports instead of per capita imports (which will be used in a robustness check in column 1 of Table 2); because the GR-caused grain imports significantly increased population growth (see column 1 of Table 5), using the per capita measure tends to underestimate the impacts of RDA.

The coefficient α_1 captures the causal effect of RDA on grain imports if RDA is exogenous. However, RDA could be endogenous for two reasons. First, it is possible that both RDA and grain imports are affected by omitted country-specific time-varying factors, which cannot be accounted for by the fixed effects included. For example, both RDA and grain imports could be determined by the country-specific evolution of food demand caused by unobservable time-varying factors. Second, the adoption rate of HYVs (and thus RDA constructed from it) could be directly affected by grain imports. For example, countries that import more grain might have a lower incentive to adopt HYVs and thus end up with higher RDA. Two IVs will be used to address the potential endogenous bias.

Note that the baseline analysis transforms net grain imports into natural logs in order to mitigate heteroskedasticity and facilitate the interpretation of the coefficient (as a percentage effect). As the log of a negative number is undefined, I calculate the log net

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[7] Nevertheless, the identification of this article is not primarily driven by comparing across continents. In a robustness check presented in column 4 of Table 2, I show that controlling for the continent-by-year fixed effects does not alter the main finding.

grain imports as $-\ln|I_{it}|$ when the country is a net grain exporter.[8] One concern might be that the log transformation could create jumps in the variable around zero and thereby artificially increase the variance in countries that switched from being net exporters to net importers (or vice versa). This concern is relevant, but only when the net import value is small, which is not the case for most developing countries examined in this study (see Fig. 4). In a robustness check (Table 1 column 7), I excluded all the 17 countries that switched from being net exporters to being net importers or vice versa between 1965 and 2000. The resulting estimate is very similar. In addition, a comparable effect is estimated when using per capita grain imports (without taking logs) as the dependent variable in another robustness check (column 1 of Table 2).

Note also that because the year fixed effects included in model (2) account for any inter-annual changes that are common across countries, the coefficient of RDA_{it} mainly captures the effect of $-HYV_{it}$ (because $\overline{HYV}_{-it}$ is almost constant across countries in a given year). In other words, the regression model can be simplified to

$$\ln I_{it} = \upsilon_i + \tau_t + \alpha_2 HYV_{it} + Z_{it}\lambda + \varepsilon'_{it} \quad , \tag{3}$$

and we expect that $\alpha_2 \approx -\alpha_1$. However, regression model (2) facilitates understanding and interpretation of the estimated effect. Specifically, a significantly positive coefficient of RDA_{it} from model (2) is naturally interpreted to mean that countries that are more disadvantaged in adopting HYVs import more grains. In contrast, a significantly negative coefficient of HYV_{it} from model (3) could be interpreted to mean that countries that adopted more HYVs experienced more declines in grain imports, which is not the case for most developing countries examined in this study (see Figs. 5 and 8).

4.4. *Instrument variables*

4.4.1. *The IV constructed from agro-climatic suitability*

To address the endogeneity concern, I construct two IVs for RDA. The first is constructed based on cross-country variation in agro-climatic suitability for growing HYVs. As detailed in Appendix D.1, the first IV is constructed in three steps, based on the agro-climatic suitability data obtained from the Global Agro-Ecological Zone (GAEZ) dataset. First, in a panel model with country- and year-fixed effects, I regress the real HYV adoption rate of each crop on the interactions between the crop's agro-climatic suitability (measured by yields under the modern high inputs) in each country and a full set of year dummies. Second, I predict the HYV adoption rate of each crop in each year based on the coefficient estimates of interactions from the panel model and then use the predicted values to calculate the country-level predicted adoption rate of HYVs. Finally, I construct the IV, the predicted RDA (pRDA), as the difference between the average predicted HYV adoption rate of all other developing countries and the predicted HYV adoption rate of the country. As presented in Figure A.2, pRDA is positively and strongly correlated with RDA, consistent with the observation of Costinot and Donaldson (2012). In a robustness check (column 3 of Table 2), I also use an IV constructed based on the predicted yield difference between high (modern) and low (traditional) inputs of each crop instead of only on the yield under the modern high inputs.

The pRDA is plausibly exogenous to grain imports because a country's agro-climatic conditions should not be affected by the outcome of interest or by its omitted time-varying determinants. Based on similar arguments, the agro-climatic suitability has been frequently used to construct IVs for agricultural productivity (e.g., Nunn and Qian, 2011; Bustos et al., 2016). Fig. 9 presents evidence supporting the exogeneity of pRDA. Specifically, I estimate the following flexible version of model (2):

$$\ln I_{it} = \upsilon_i + \tau_t + \sum_{k=1961}^{2016} \alpha_k \overline{IV}_i \times year_t^k + Z_{it}\lambda + \varepsilon_{it} \quad , \tag{4}$$

where $\overline{IV}_i$ denotes the 1965–2000 average of $pRDA_{it}$, and $year_t^k$ is a full set of year dummies from 1961 to 2016 (the dummy of 1965 is omitted). All other variables are the same as those defined in model (2). The flexible model is estimated using data from 1961 to 2016 for the 75 countries.

If the IV captures only the effect of the GR but not the effect of pre-existing differential trends across countries, the flexible model should find that the IV had no effect on grain imports prior to the GR. Indeed, Panel A of Fig. 9 shows that pRDA had no significant effect on grain imports prior to 1965. In addition, the figure confirms that pRDA significantly increased grain imports shortly after the GR. However, an obvious drawback of this test of exogeneity is that we only have five years of pre-GR data. I have visited various databases that provide pre-1960 trade data (e.g., TRADHIST, RICardo, and COMTRADE) and found that earlier grain trade data are generally not available. This drawback motivates me to adopt a second IV, for which the exogeneity can be more rigorously tested.

Panels B and C of Fig. 9 provide additional evidence supporting the exogeneity of the IV. As income and population are important determinants of grain imports, it would be relieving to find out that pre-GR trends in income and population are not correlated with the IV. To do so, I estimate versions of model (4) that use log GDP per capita (Panel B) or log population (Panel C) as the dependent variable. As the data for GDP and population are available for all sample countries starting from 1950, much longer pre-GR trends can be tested. The estimated effects on GDP per capita and population are close to zero and statistically insignificant prior to the GR, again supporting the exogeneity assumption. Consistent with the main findings of this article, the estimates also indicate that after the GR, countries more disadvantaged in adopting HYVs (with larger pRDA) experienced a significant decline in GDP per capita and a significant increase in population.[9]

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[8] Because no country in the sample has zero net grain imports, this transformation does not lead to missing values.

[9] As detailed in Section 5, because pRDA is correlated with domestic HYV adoption, the estimated effects presented in Panels B and C cannot be fully attributed to the relative disadvantage in adopting HYVs; however, this fact does not undermine these tests of exogeneity.

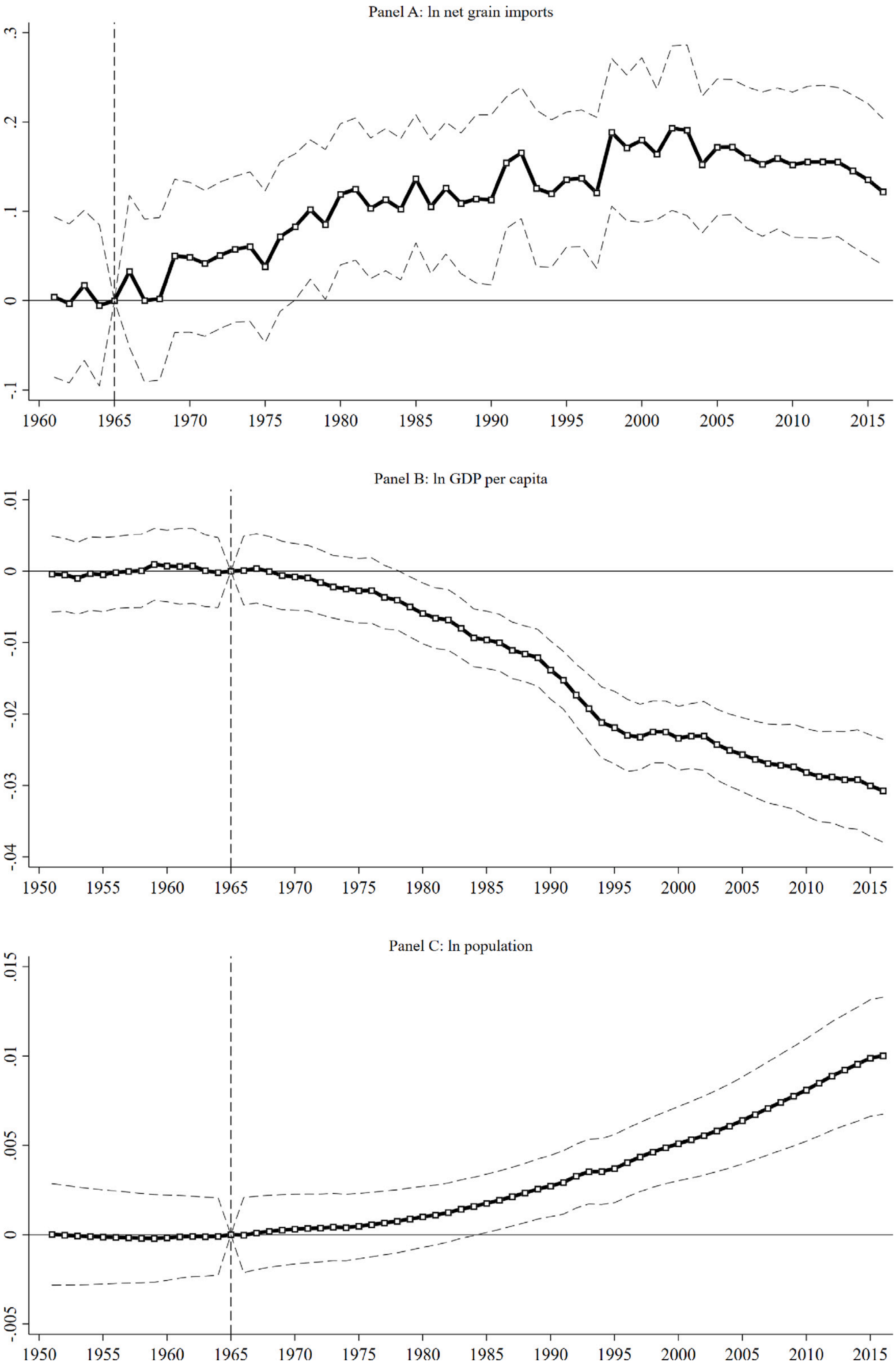

Fig. 9. Flexible estimates of the effect of pRDA on logs of net grain imports, GDP per capita, and population.

Notes: This figure presents the estimates from model (4). The dependent variables in Panels A, B, and C are logs of net grain imports, GDP per capita, and population, respectively. The data for grain imports are from 1961 to 2016, and the data for GDP per capita and population are from 1950 to 2016. Each dot on the solid line is a point estimate of α_k, and the broken lines indicate the corresponding 95% confidence intervals.

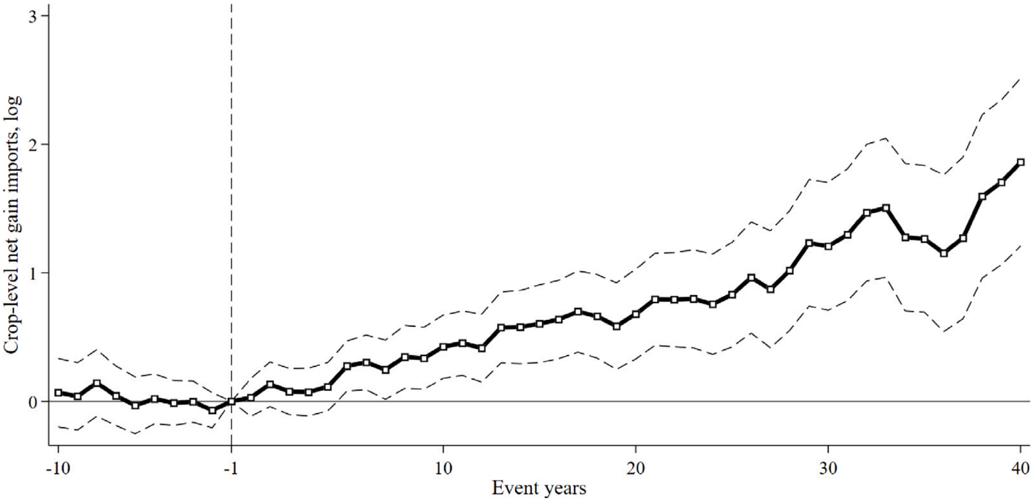

Fig. 10. Crop-level event-study estimates of the effect of HYVs on net grain imports.
Notes: The estimation is based on Eq. (5). The dependent variable is log net imports of each of the 25 crops (16 treatment crops and 9 pure-control crops). The sample period is 1961–2016. The omitted comparison event year is the year before an HYV release (vertical line). Each dot on the solid line is a point estimate of β_s, and the broken lines indicate the corresponding 95% confidence intervals. Standard errors are clustered at the crop-by-country level.

4.4.2. The IV constructed from differential HYV release years

The second IV is constructed based on the differential release years of HYVs across crops, closely following Gollin et al. (2021). As presented in Figure A.3, the HYV release years varied substantially across crops. Gollin et al. (2021) argued that the release years of HYVs are exogenous to individual developing countries. They used the staggered HYV release to estimate the effect of the GR on individual crop yields and then combined the estimates with the pre-GR production share of each crop to determine the country-level predicted effect of the GR on aggregate crop yields (i.e., the predicted GR). I follow their method to calculate the predicted GR and then use it to construct the second IV: the predicted differential GR (pdGR), which is calculated as the difference between the average predicted GR across all other developing countries and the predicted GR of the country. Details of the IV construction are presented in Appendix D.1. Importantly, the construction is based on the data from 16 mandate crops of the International Agricultural Research Centers and 9 pure-control crops (for which HVYs have never been developed). As shown in Figure A.4, pdGR is positively and strongly correlated with RDA.

The second IV is plausibly exogenous because it is constructed based on the exogenous timing of the HYV release. The exogeneity can be verified based on the idea that if the release years of HYVs are exogenous (and thus the IV constructed from it), we should observe that the impact of HYV on the imports of specific crops shows up only after the release year of HYV for that crop. Specifically, I test the exogeneity of HYV introduction on grain imports based on the following event-study regression:

$$\ln I_{ijt} = \sum_{s\in T_j} \beta_s \cdot 1_{jt}^{t=\tau_j+s} + \delta \ln harea_{ijt} + \mu_{ij} + \mu_{it} + \varepsilon_{ijt}, \tag{5}$$

where $\ln I_{ijt}$ is the log net imports of crop j in country i and year t. The two terms μ_{ij} and μ_{it} denote, respectively, country-by-crop and country-by-year fixed effects, meaning that only within-country time variation in relative imports remains. The effect of harvested area adjustments is controlled for by $\ln harea_{ijt}$. The key explanatory variable is an indicator function $1_{jt}^{t=\tau_j+s}$ that takes a value of one s years after the release year of the first HYV of crop j, which I denote τ_j. The coefficient β_s measures the amount by which the relative net imports of crop j in the average country has changed s years after the introduction of HYVs relative to a benchmark year. The benchmark is set as the year before introduction of HYVs, so I define $T_j = \{-10, \dots, -2, 0, 1, \dots, 2016 - \tau_j\}$.

If HYVs provided the only global shock to relative grain imports in the specified release years, we should expect $\beta_s = 0$ before the release of the first HYV of crop j (i.e., for $s < 0$). In addition, because the GR increased grain imports of the average developing country, we expect $\beta_s > 0$ after the release of the first HYV. Fig. 10 presents the estimation results. Consistent with the exogeneity assumption, the estimated coefficients are close to zero and statistically insignificant for event years before the first HYV release. In addition, the figure shows a clearly increasing trend in relative imports of a crop after the first HYV of the crop was released. The effect on net grain imports increases gradually and becomes statistically significant after about five years of HYV release, reflecting the fact that the adoption of HYVs is gradual.

Note that the IVs constructed above are unlikely to be confounded by other concurrent events, such as tariff reductions, wars, and birth control policies. First, the model has included the year fixed effects to account for concurrent events that are common to all developing countries. Second, given that the timing of crop-level GR is exogenous to individual developing countries, it is impossible for country-specific concurrent events to determine the timing of the GR. If country-specific events are systematically correlated with the timing of the crop-level GR, it is likely that these events are the outcomes of the GR. In this case, one should not control for these events in order to avoid the over-control bias.

Note also that the exogeneity of the above IVs is not undermined by the fact that some developing countries have also made efforts to improve domestic crop varieties after the GR. There was considerable research in developing countries, such as India and China, during the 1980s and 1990s directed at adapting and improving the initial HYVs developed at the international agricultural research centers. For example, Evenson and Gollin (2003b) estimate that the first generation of improved rice varieties would have been planted on only about 35% of rice acreage in India, whereas subsequent generations increased adoption to more than 80%. However, because the IVs are constructed based on variations from the initial agro-climatic suitability for cultivating the GR crops or from the exogenous release dates of the initial GR varieties, they are unlikely to be affected by the later efforts of individual developing countries to improve crop varieties.

4.5. *Estimation results*

Table 2 presents the estimation results of model (2). In each column, the round brackets report the heteroskedasticity-robust standard error, and the square brackets report the 95% confidence intervals calculated based on the wild-cluster restricted bootstrap procedure proposed by Cameron et al. (2008) (with 1000 replications and clustered at the country level). The bootstrapped standard errors address the concern that the IVs are generated regressors. Column 1 reports the OLS estimates, and the remaining columns report the 2SLS estimates. The reported first-stage F-statistics of the 2SLS estimations are all large, suggesting that the IVs have sufficient explanatory power in the first-stage estimation. When both IVs are used (in columns 4–7), the reported J-statistics (and the accompanying P-value) of the Sargan–Hansen test indicate that the joint null hypothesis that the two IVs are valid is not rejected.

The OLS estimate reported in column 1 suggests that a 1% increase in RDA leads to 7.8 percentage points higher grain imports, and this effect is statistically significant at the 1% level. The 2SLS estimate reported in column 2 (using the predicted RDA as the IV) is very close to the OLS estimate. This finding is not surprising because RDA is primarily determined by the exogenous agro-climatic conditions and HYV release years. Because the average RDA for GR-disadvantaged (GR-advantaged) countries was 39.4% (−17.0%) in 2000, the 2SLS estimate implies that the GR increased grain imports (grain exports) by 315 percentage points (136 percentage points) relative to the 1965 level for an average GR-disadvantaged (GR-advantaged) country.[10] The GR-caused grain imports in an average GR-disadvantaged country account for about one-third of the observed (11-fold, Fig. 8) increase in grain imports over this period.[11]

Columns 3–7 of Table 1 provide robustness checks. Column 3 adopts the IV constructed from the release years of HYVs (i.e., pdGR) and shows a slightly smaller effect. Column 4 uses the two IVs at the same time and shows a comparable result. Column 5 additionally controls for nine determinants of grain imports: log GDP per capita, log population, share of agriculture in GDP, annual mean temperature, annual total precipitation, soil rooting condition index, the dummy of landlocked, the most important colonizer in the history, and the measure of political stability.[12] Controlling for these important determinants of grain imports has a very small effect on the 2SLS estimate. Column 6 excludes the nine countries (Argentina, Thailand, India, Vietnam, China, Pakistan, Myanmar, Uruguay, and Paraguay) that were net grain exporters in 2000. The resulting estimate is slightly smaller and has no statistically significant difference from the baseline estimate in column 5, suggesting that the estimated effect is not primarily driven by grain-exporting countries. Column 7 excludes the 15 countries that switched from being net exporters to being net importers or vice versa between 1965 and 2000. This is to address the concern that the log transformation of net grain imports may create jumps in the variable around zero, which artificially increases its variance in countries that switched from being net exporters to net importers or vice versa. The resulting estimate is nearly identical to the baseline estimate, suggesting that this concern is minor.

Table 2 (columns 1–5) provides additional robustness checks for the baseline 2SLS estimate. Column 1 further addresses the concern of log transformation by using per capita net grain imports (without taking logs) as the dependent variable. The resulting estimate also suggests that higher RDA significantly increases grain imports, although the magnitude of the effect is not directly comparable due to different units used. Note that this measure of grain imports is not preferred because RDA also affects population growth (see column 1 of Table 5), making the per capita effect difficult to interpret. Column 2 uses the log import-to-consumption ratio of the 11 food crops as the measure of grain imports and finds a similar percentage effect. Again, because consumption is endogenous, this measure is not preferred. Column 3 adopts an alternative IV constructed based on the yield potential difference between high and low inputs. The resulting estimate is only slightly larger than the baseline estimate. Column 4 additionally controls for the continent-by-year fixed effects to address the concern that the estimated effect could be primarily driven by comparing across

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[10] The estimated percentage effect is much larger in GR-disadvantaged countries because the average size of GR-disadvantaged countries is much smaller than that of the GR-advantaged countries (which include large countries, such as India and China). I find that the total GR-caused grain imports and exports from these two groups of countries were approximately equal.

[11] The aggregate quantification extrapolated from cross-sectional estimates presented here and presented in the following sections is based on the assumption that the effects are linear. A major concern of this assumption is that the effect could be primarily driven by comparing across the GR-advantaged and GR-disadvantaged countries, which implies a non-linear effect across these two groups of countries. I relieve this concern by showing that the estimated effects are comparable when excluding the GR-advantaged countries from the sample (see column 6 of Table 1 and column 1 of Table 4).

[12] The last four time-invariant variables are interacted with a full set of year dummies. The measure of political stability is only available for years after 1990, so I control for the mean of this variable and treat it as time invariant. I have tried to control for the subsets of these variables or using alternative measures of climatic variables (e.g., degree-days and temperature bins) and found very similar results. Details of these control variables are presented in Table A.2.

Table 1
Effect of RDA on grain imports (dependent variable: log net grain imports).

	(1) OLS	(2) 2SLS (IV = pRDA)	(3) 2SLS (IV = pdGR)	(4) 2SLS (IV = pRDA, pdGR)	(5) 2SLS, including nine controls (IV = pRDA, pdGR)	(6) 2SLS, excluding net exporters (IV = pRDA, pdGR)	(7) 2SLS, excluding "switched" countries (IV = pRDA, pdGR)
RDA	0.078***	0.080***	0.068***	0.075***	0.080***	0.067***	0.082***
	(0.013)	(0.023)	(0.026)	(0.021)	(0.030)	(0.024)	(0.019)
	[.050, .105]	[.036, .123]	[.015, .121]	[.032, .118]	[.013, .141]	[.015, .117]	[.041, .122]
Country FE and year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
First-stage F-statistic		94.2	81.3	60.1	22.3	52.8	55.7
Hansen's J-statistic				0.30	1.59	2.60	0.67
(P-value)				(0.59)	(0.20)	(0.10)	(0.41)
Observations	675	675	675	675	675	594	540
Countries	75	75	75	75	75	66	60
R-squared	0.663	0.663	0.663	0.663	0.674	0.557	0.781

Notes: The table presents the estimates of model (2). Column 1 presents the OLS estimate, and the remaining columns present the 2SLS estimates. Column 2 use pRDA as the IV, column 3 uses pdGR as the IV, column 4 includes both IVs, column 5 additionally includes nine control variables, column 6 excludes countries that were net grain exporter in 2000, and column 7 excludes countries that switched from being net grain exporters to net grain importers or vice versa from 1965 to 2000. The round brackets report the robust standard errors, and the square brackets report the 95% confidence intervals calculated based on the wild-cluster restricted bootstrap procedure proposed by Cameron et al. (2008) (with 1000 replications and clustered at the country level). Significance levels are $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

continents. The resulting estimate is larger, presumably because the estimation is now based mainly on the remaining within-continent cross-country variation.[13] Column 5 extends the sample to 86 developing countries by including 11 countries with 1960 populations smaller than 1 million. The resulting estimate is very close to the baseline estimate.

The last two columns of Table 2 verify the prediction that, for developing countries, a relative disadvantage in adopting HYVs also increases the imports of manufactured goods and increases the exports of raw materials. These estimations are based on modified versions of model (2) that use the log net manufacturing imports (column 6) and log net raw material imports (column 7) as the dependent variables. The net manufacturing imports are measured by the sum of the net import values (in 2011 US$) of chemicals, basic manufactured goods, machinery and transport equipment, and miscellaneous manufactured goods. The net raw material imports are measured by the sum of the net import values of fuel, ores, and metals. The estimates suggest that a 1% higher RDA increases the net import of manufactured goods by 8.6 percentage points and increases the net export of raw materials by 19.6 percentage points. Note that the sample sizes in these estimations are much smaller because data on the trade of these products are unavailable in early years for many developing countries.

5. Effect of grain imports on GDP per capita

5.1. Estimation method

I estimate the effect of grain imports on GDP per capita based on:

$$\ln y_{it} = \upsilon_i + \tau_t + \beta_1 \ln I_{it} + Z_{it}\lambda + \mu_{it} \ , \tag{6}$$

where $\ln y_{it}$ is the log real GDP per capita (in 2011 US$) in country i and year t; $\ln I_{it}$ is the log net grain imports as defined above; Z_{it} is a vector of control variables (will be introduced in the estimation); υ_i and τ_t denote the country- and year-fixed effects, respectively; β_1 and λ are the coefficients; and μ_{it} is an error term. The country-fixed effects account for the confounding effects of any time-invariant factors, while the year-fixed effects account for any annual shocks that are common across countries. I will also use model (6) to estimate the effect of grain imports on various other economic outcomes and welfare measures: the birth rate, log population, life expectancy, infant mortality, years of schooling, per hectare grain output, per capita physical capital, per capita grain consumption, per capita household consumption, poverty rate, and Gini coefficient.

The OLS estimate of β_1 tends to be biased by omitted variables and reverse causality. Although the model includes country- and year-fixed effects, it cannot address the bias from omitted country-specific, time-varying factors that are correlated with both grain imports and income. In addition, it is likely that higher incomes promote grain imports by increasing the food demand and limiting agricultural labor supply. This positive reverse effect tends to bias the negative effect of grain imports on income towards zero. Therefore, it is necessary to use an excluded IV for grain imports in model (6).

Note that although the IVs constructed in the last section (i.e., pRDA and pdGR) are strongly correlated with grain imports, they cannot be used as IVs for grain imports in model (6). This is because, according to Eq. (1), these IVs are necessarily correlated

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[13] As within-continent costs of trade are smaller than those cross continents, the impact of RDA on grain trade across countries within the same continent is expected to be larger.

Table 2
Robustness checks of the effect of RDA on grain imports.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable	Per capita net grain imports	Log grain import-to-consumption ratio	log net grain imports	log net grain imports	log net grain imports	log net import of manufactured goods	log net import of raw materials
	2SLS (IV = pRDA, pdGR)	2SLS (IV = pRDA, pdGR)	2SLS (IV = difference between high and low inputs)	2SLS , including continent-by-year fixed effects (IV = pRDA, pdGR)	2SLS, 86 countries (IV = pRDA, pdGR)	2SLS (IV = pRDA, pdGR)	2SLS (IV = pRDA, pdGR)
RDA	0.060*** (0.023) [.010, .108]	0.067*** (0.022) [.019, .119]	0.094*** (0.032) [.026, .157]	0.147*** (0.045) [.044, .250]	0.082*** (0.025) [.029, .136]	0.086*** (0.024) [.029, .156]	−0.196*** (0.039) [−.30, −.10]
Country FE and year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Nine control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
First-stage F-statistic	29.6	29.6	54.6	17.9	59.7	16.1	12.2
Observations	675	675	675	675	774	390	364
Countries	75	75	75	75	86	59	51
R-squared	0.790	0.346	0.672	0.669	0.666	0.736	0.770

Notes: The table presents robustness checks for the baseline 2SLS estimates reported in column 5 of Table 1. The dependent variable is per capita net grain imports in column 1, log import-to-consumption ratio in column 2, log net grain imports in columns 3–5, log net imports of manufactured goods in column 6, and log net import of raw materials in column 7. The differences between columns 3–5 are that column 3 uses the IV constructed based on the yield potential difference between high and low inputs, column 4 additionally control for the continent-by-year fixed effects, and column 5 extend the sample to 86 developing countries. Columns 6 and 7 estimate the effect of RDA on the net imports of manufactured goods and raw materials, respectively, in the same model setting. The round brackets report the robust standard errors, and the square brackets report the 95% confidence intervals calculated based on the wild-cluster restricted bootstrap procedure proposed by Cameron et al. (2008) (with 1000 replications and clustered at the country level). Significance levels are $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

with domestic HYV adoption and thus could affect income not only through grain imports; using them in model (6) tends to partly account for the effect of domestic HYV adoption and thus overestimate the effect of grain imports. For this reason, the next subsection constructs Bartik IVs that affect domestic income only through grain imports. Appendix Table A.4 presents the 2SLS estimates of model (6) using pRDA and pdGR as the IVs, and the estimated negative effect of grain imports is indeed much larger than that based on the Bartik IVs (Table 3).

5.2. Bartik IVs

I construct the IV for grain imports based on the grain supply shocks from the GR and the bilateral distance to grain exporters. Specifically, the IV is constructed as the distance weighted predicted GR of net grain exporters:

$$\text{GR-Bartik}_{it} \equiv \frac{\sum_d L_{id} \times pGR_{dt}}{\sum_d L_{id}}, \tag{7}$$

where pGR_{dt} is the predicted GR of net grain-exporting country d in year t, and L_{id} is the distance between country i and country d. The predicted GR (pGR_{dt}) is the same as that used in the last section based on the differential HYV release years across crops and the initial crop composition of each country). The distance used is the bilateral distance derived from the database constructed by Mayer and Zignago (2011).

Country d includes all 34 net grain-exporting countries in 1964 (the year before the GR), and country i includes the 75 developing countries examined in this study. Among the 34 net grain exporters identified in 1964, 16 of them belong to the 75 developing countries, and the remaining 18 countries are developed countries excluded from the main analysis. Note that when a sample country i is a net exporter, its GR has no contribution to the IV constructed for itself because the distance $L_{id} = 0$ if $i = d$. Including the 18 net exporters outside the 75 developing countries helps to substantially increase the variation in the grain supply shocks. Recall that developed countries are excluded from the main analysis partly due to the concern that the GR was not exogenous to them. Nevertheless, the GR also affected developed countries, and the country-level predicted GR can also be calculated for them based on equation (15). Including developed countries when constructing the Bartik IV does not undermine the identification because the GR in developed countries is exogenous to developing countries.

The IV constructed in (7) follows the logic of the standard Bartik (shift-share) IV, which has been widely used in the recent economics literature (Acemoglu et al., 2019; Adao et al., 2019; Greenstone et al., 2020; Borusyak et al., 2022). The "shift" in the IV is the differential shocks to grain productivity across grain exporters due to the GR. Because the shocks from the GR are constructed based on HYV release years, which are exogenous to developing countries, the "shift" is exogenous to the 75 developing countries. The "share" of the IV is the distance of each developing country to grain exporters, based on the idea that productivity shocks to a grain exporter should have larger effects on countries that are closer to the exporter. Note that I define net grain-exporting countries as those before the GR (in 1964) to avoid the endogenous effect of the GR on the "share" of the IV.[14] Table A.5 shows that the Bartik IV has a significantly positive and robust effect on grain imports in developing countries.

Importantly, the Bartik IV excludes the confounding effect of domestic HYV adoption. Foreign grain supply shocks should not be directly correlated with the domestic HYV adoption rate, which is especially true when the year-fixed effects are included to account for common shocks from the GR. In addition, as widely assumed in the trade literature (e.g., Frankel and Romer, 1999), the distance to other countries can only affect domestic economic outcomes through trade. Different from the traditional distance IVs used in cross-sectional studies, which are sensitive to omitted variables (Rodriguez and Rodrik, 2000; Feyrer, 2019), the Bartik IV constructed here employs the time variation from supply shocks and thus enables including the country-fixed effects in the model to account for the omitted variables.

One might still be concerned that constructing the Bartik IV directly from the supply shocks from the GR (i.e., the predicted GR) may introduce a correlation between foreign GR and domestic HYV adoption. If this is true, the estimated effect of grain imports could still partly account for the effect of domestic HYV adoption. However, this concern should be minor because the estimation model includes the year-fixed effects to account for common shocks to all countries, which implies that the effect is estimated based on differential GR of foreign countries. In a robustness check (column 5 of Table 3), I show that controlling for domestic HYV adoption rates does not significantly affect the 2SLS estimate of the coefficient of grain imports.

Nevertheless, to further address this concern, I construct another Bartik IV based on the observed real supply shocks instead of the predicted GR:

$$\text{Supply-Bartik}_{it} \equiv \frac{\sum_d L_{id} \times Exports_{dt}}{\sum_d L_{id}}, \tag{8}$$

where the only difference from Eq. (7) is that the "shift" ($Exports_{dt}$) is measured by net grain exports observed in each year for the 34 net grain exporters. It turns out that the 2SLS estimate based on this Supply-Bartik IV is nearly identical to that based on the GR-Bartik IV (see columns 3 and 4 of Table 3), rejecting the possibility that the 2SLS estimate based on the GR-Bartik IV is primarily driven by domestic HYV adoption. I test the exogeneity of the Supply-Bartik IV by estimating a version of the flexible model (4) that uses the average of the Supply-Bartik IV over 1965–2000 (interacted with a full set of year dummies) as the explanatory variable. As reported in Panel B of Figure A.5, the IV has no effect on GDP per capita before the GR but significantly reduces it shortly after the GR. These findings confirm that no major country-specific supply shocks beside the GR occurred during this period.

One might also be concerned that the Bartik IVs constructed based on the grain supply shocks from the GR (Eq. (7)) or the observed real supply shocks (Eq. (8)) are peculiar in that these IVs show a monotonically increasing trend. This concern is alleviated by including year-fixed effects in the model, which remove productivity increases common to grain-exporting countries and allow the estimation to focus on country-specific relative changes in grain exports.[15] Nevertheless, I further address this concern by adopting an alternative IV constructed based on non-monotonic climatic shocks in the 34 net grain-exporting countries. Specifically, I construct the following Bartik IV using a measure of positive precipitation shock:

$$\text{Climatic-Bartik}_{it} \equiv \frac{\sum_d L_{id} \times Shock_{dt}}{\sum_d L_{id}}, \tag{9}$$

where the only difference from Eq. (7) is that the "shift" ($Shock_{dt}$) is a measure of positive precipitation shocks that occurred in the 34 net grain-exporting countries. I follow the literature (e.g., Ashraf and Michalopoulos, 2015; Miller et al., 2021; Huang et al., 2023) to measure the positive precipitation shock in each year as the number of months with precipitation that exceeds one standard deviation above the long-run average precipitation for the same month.[16] Considering that there might be lagged effects of precipitation shocks on grain exports, $Shock_{dt}$ in Eq. (9) is calculated as the average precipitation shock over the past three years (specifically, the average over t, $t-1$, and $t-2$). As presented in column 4 of Table A.5, the Bartik IV constructed in (9) shows a significantly positive effect on the grain imports of grain importers. Additionally, the First-stage F-statistic reported in Column 5 of Table 3 (i.e., 13.9) suggests that this IV is not weak. I have also constructed similar Bartik IVs based on negative precipitation shocks, positive and negative temperature shocks, annual mean temperature, and annual total precipitation. However, these alternative climate-shock IVs are weaker than the one constructed based on positive precipitation shocks.[17]

In further robustness checks, two additional Bartik IVs are adopted. The first is constructed based on the top 20 net grain-exporting countries in 1964, and the second is based on net grain-exporting countries observed in each year. The first IV addresses

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[14] In fact, Borusyak et al. (2022) argue that the exogeneity of the "share" is not a necessary condition for the validity of the shift-share IV.

[15] A potential concern of including year-fixed effects in the regression model is that they could account for most of the time-variation in the IVs. Fortunately, Appendix Figure A.6 shows substantial changes in the ranking of net grain exporters over the sample period. This implies that there were significant country-specific relative changes in grain exports for identification purposes, even after accounting for the year-fixed effects. Furthermore, Appendix Table A.6 presents regressions that exclude the year-fixed effects and still find significantly negative effects of grain imports on log GDP per capita.

[16] To be more specific, for a given country in a given year, if there is at least one month with total precipitation exceeding one standard deviation from the average total precipitation for the same month over the past 30 years, the shock indicator takes on a value of 1; otherwise, it remains 0. The shock indicator is then calculated as the number of months in each year with a positive precipitation shock. The climate data used in this calculation is obtained from the Climatic Research Unit, which is one of the most widely used observed climate datasets produced by the UK's National Centre for Atmospheric Science at the University of East Anglia.

[17] I only use this IV in a robustness check because I am concerned that it may result in an overestimation of the negative impact of grain imports. This is because countries that import grain have less time to adjust to the rapid changes in grain imports caused by climatic shocks, compared to the gradual increases caused by the GR. As shown in column 5 of Table 3, I do find a larger negative impact when using the precipitation shock as the IV.

Table 3
Effect of grain imports on log GDP per capita.

	(1) OLS	(2) 2SLS (IV = GR Bartik)	(3) 2SLS, including seven controls (IV = GR Bartik)	(4) 2SLS (IV = Supply Bartik)	(5) 2SLS (IV = Climatic Bartik)	(6) 2SLS, controlling for HYV (IV = GR Bartik)	(7) 2SLS (IV = Top 20 Bartik)	(8) 2SLS (IV = Varying exporters Bartik)	(9) 2SLS, interacting with resource rents (IV = GR Bartik)
Log net grain imports	−0.017***	−0.121***	−0.115***	−0.111***	−0.189***	−0.097***	−0.108***	−0.091***	−0.078***
	(0.004)	(0.035)	(0.036)	(0.024)	(0.028)	(0.050)	(0.025)	(0.027)	(0.027)
		[−.21, −.05]	[−.24, −.04]	[−.16, −.06]	[−.32, −.08]	[−.17, −.03]	[−.16, −.05]	[−.16, −.03]	[−.13, −.02]
Log grain imports ×1970 resource rents									−0.006*** (0.002) [−.01, −.002]
Country and year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
First-stage F-statistic		12.9	11.5	30.4	13.9	15.5	26.5	16.9	12.9
Observations	675	675	675	675	675	675	675	675	675
Countries	75	75	75	75	75	75	75	75	75
R-squared	0.930	0.845	0.863	0.861	0.698	0.881	0.865	0.887	0.931

Notes: The table presents the estimates of model (6). Column 1 presents the OLS estimate, and the remaining columns present the 2SLS estimates based on the Bartik IVs. Column 2 uses the IV constructed based on the predicted GR, column 3 uses the same IV and controls for seven potential confounding factors, column 4 uses the IV constructed based on the observed grain supply shocks, column 5 uses the IV constructed based on the precipitation shocks in the grain exporting countries, column 6 controls for the HYV adoption rate, column 7 uses the IV constructed based on the top 20 net grain exports in 1964, column 8 uses the IV constructed based on the net grain exporters in each year, and column 9 includes the interaction between grain imports and the natural resource rents in 1970. The round brackets report robust standard errors, and the square brackets report the 95% confidence intervals calculated based on the wild-cluster restricted bootstrap procedure (with 1000 replications and clustered at the country level). Significance levels are ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$.

the concern that some of the 34 grain-exporting countries in 1964 export a negligible amount of grains and thus generate no real supply shocks. Similarly, the second IV excludes countries that switched from net grain exporters to net grain imports during 1965–2000 and thus is more relevant for capturing the effect of the supply shock (although at the cost of introducing endogenous “share”). It turns out that the 2SLS estimates are quite comparable when using these alternative Bartik IVs.

5.3. Estimation results

Table 3 presents the estimation results of model (6). The OLS estimates presented in column 1 suggest that a 1 percentage point increase in net grain imports reduces the GDP per capita by 0.017 percentage points, and this effect is statistically significant at the 1% level. However, the OLS estimate is likely to be biased toward zero because of reverse causality: higher income could lead to more grain imports by raising per capita food consumption and the opportunity costs of labor in agriculture. The 2SLS estimates presented in the remaining columns are much larger, confirming the bias of the OLS estimate.

Column 2 presents the 2SLS estimates based on the GR-Bartik IV constructed in Eq. (7). The first-stage F-statistic reported is reasonably large (12.9), suggesting that the IV has sufficient explanatory power in the first-stage regression.[18] The 2SLS estimate indicates that a 1 percentage point increase in net grain imports reduced the GDP per capita by 0.121 percentage points, and this estimate is statistically significant at the 1% level. Recall that for an average GR-disadvantaged (GR-advantaged) country, the GR increased the grain imports (grain exports) by 315 percentage points (136 percentage points) by 2000. Therefore, the GR-caused grain trade reduced (increased) the GDP per capita in an average GR-disadvantaged (GR-advantaged) country by 38.1 percentage points (16.5 percentage points) by 2000 relative to that in 1965. The implication of these estimates for cross-country income divergence will be discussed later.

Columns 3–8 of Table 3 provide robustness checks for the 2SLS estimate. Column 3 additionally controls for seven potential confounding factors: log population, share of agriculture in GDP, harvested areas of the GR crops, log GDP per capita in 1964, the dummy of landlocked, the most important colonizer in the history, and a measure of political stability (the last four time-invariant variables are interacted with a full set of year dummies). The resulting estimate is very close to that reported in column 2. I also tried to control for subsets of these variables and found very similar results. Importantly, the preferred model setting is the one that includes no control variables except for the country and year fixed effects. As detailed above, the GR-Bartik IV is constructed based on factors that are exogenous to individual developing countries (i.e., the predicted GR of and geographic distance to grain exporters), and we have no reason to believe that domestic income determinants could affect this IV. More importantly, as illustrated in the following mediation analysis, grain imports could affect domestic income through various time-varying factors; controlling for them could partly account for the true effect of grain imports and lead to an over-control bias.

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[18] The corresponding first-stage estimates are reported in Appendix Table A.5.

Table 4
Robustness checks for the effect of grain imports on income.

	(1) Excluding net grain exporters	(2) Excluding bottom 10 importers	(3) Excluding top 10 importers	(4) Extending to 86 developing countries	(5) Agricultural GDP per capita	(6) Manufacturing GDP per capita	(7) Service GDP per capita
Log net grain imports (IV = GR Bartik)	−0.115*** (0.027) [−.17, −.06]	−0.137*** (0.035) [−.23, −.06]	−0.123*** (0.025) [−.18, −.07]	−0.076*** (0.021) [−.12, −.03]	−0.058*** (0.019) [−.09, −.01]	−0.067** (0.029) [−.12, −.01]	−0.095*** (0.026) [−.15, −.04]
Country FE and year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
First-stage F-statistic	19.4	16.6	21.5	26.9	19.1	12.6	23.6
Observations	594	585	585	774	675	639	639
Countries	66	65	65	86	75	71	71
R-squared	0.870	0.814	0.822	0.909	0.730	0.921	0.898

Notes: The table presents robustness tests for the 2SLS estimates presented in column 2 of Table 3. Column 1 excludes countries that were net grain exporters in 2000, columns 2 and 3 respectively exclude countries that were the bottom 10 or top 10 grain importers (measured by the average import-to-consumption ratio during 1960–2000), column 4 extends the sample to 86 developing countries where the data are available, and columns 5–7 estimate the effects on sectoral GDP per capita. The round brackets report robust standard errors, and the square brackets report the 95% confidence intervals calculated based on the wild-cluster restricted bootstrap procedure (with 1000 replications and clustered at the country level). Significance levels are $^{***}p < 0.01$, $^{**}p < 0.05$, and $^{*}p < 0.1$.

Column 4 uses the Bartik IV constructed based on the observed annual net grain exports of the 34 grain-exporting countries (Eq. (8)). The resulting estimate is only slightly smaller than the baseline 2SLS estimate reported in column 2, relieving the concern that the IV estimate could be primarily driven by the association between foreign GR and domestic HYV adoption. Column 5 utilizes the Bartik IV constructed based on precipitation shocks in the 34 grain-exporting countries. The estimated negative effect of grain imports on log GDP per capita is even more pronounced, alleviating concerns that the estimated significantly negative effect of grain imports is driven by the monotonically increasing nature of the baseline IV.[19] Column 6 directly addresses the concern about the bias from domestic HYV adoption by including it as a control variable. As argued above, to the extent that domestic HYV adoption is correlated with channel variables through which grain imports affect domestic income, controlling for it could lead to an over-control bias. The resulting estimate is smaller but has no statistically significant difference from the baseline estimate, suggesting that it is unlikely for the domestic HYV adoption rates to substantially bias the 2SLS estimate. Columns 7 and 8 use, respectively, the Bartik IV constructed based on the top 20 net grain exporters in 1964 and the net exporters in each year. The resulting estimates are also comparable to the baseline estimate.

The last column of the Table verifies the prediction that among countries disadvantaged in adopting HYVs, those richer in natural resources fell further behind. To do this, I examine the partial effect of the interaction between net grain imports and the natural resource rents in 1970, the earliest year for which the data on natural resource rents are available.[20] The estimated coefficient of the interaction is significantly negative, confirming the prediction that grain imports have a more negative effect in countries richer in natural resources. Specifically, the estimates suggest that a one standard deviation (6.63%) increase in natural resource rents from the mean (5.38%) would increase the marginal effect of grain imports at mean from 0.12 to 0.15. In addition, for countries ranked in the top 10% in natural resource rents (mean rents of 22.4%), the marginal effect of grain imports is as high as 0.21, about twice as large as the marginal effect for an average developing country.

Table 4 provides additional robustness checks for the baseline 2SLS estimates. Columns 1–4 examine the robustness to sample countries. Column 1 excludes countries that were net grain exporters in 2000 and finds a very similar effect, suggesting that the estimated effect is not primarily driven by grain exporters. Columns 2 and 3 exclude countries where the (1965–2000 average) import-to-consumption ratio of grains ranked in the bottom 10 and top 10 of the 75 developing countries, respectively. The resulting estimates are comparable. Column 4 extends the sample to 86 developing countries, including 11 countries with a 1960 population smaller than 1 million. The resulting estimates is about one-third smaller, suggesting that these small countries are less subject to the impact of grain imports. Columns 5–7 examine the impact on sectoral GDP per capita. Because data on sectoral population or employment are unavailable before 1991 for most developing countries, I choose to calculate the sectoral GDP per capita as the ratio of the sectoral total GDP to the total national population. Because grain imports increase population and lead to labor reallocation across sectors, the effect on each sector may be overestimated or underestimated due to this data limitation. Nevertheless, the resulting estimates still suggest that grain imports substantially reduced GDP per capita in each sector.

5.4. Mechanisms of the effect

The conceptual framework predicts that the GR-caused grain imports reduce domestic income by reducing agricultural and manufacturing outputs, increasing population growth, and retarding human capital formation. I adopt a mediation analysis (Baron and Kenny, 1986; MacKinnon, 2012) to investigate if and to what extent the effect of grain imports on GDP per capita can

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[19] Please refer to Footnote for an explanation of the larger estimated negative impact when using the climatic IV.

[20] In the 2SLS estimation, the interaction is instructed by the interaction between the IV and the natural resource rents.

Table 5
Mechanisms of the effect of grain imports on GDP per capita.

	(1)	(2)	(3)	(4)	(5)
Panel A: Regression coefficients of model (10)					
	Crude birth rate	Years of schooling	Per capita physical capital	Per hectare grain output	Log GDP per capita
Log net grain imports	2.521***	−0.279***	−0.076**	−0.166***	−0.015
	(0.268)	(0.047)	(0.039)	(0.030)	(0.017)
Crude birth rate					−0.011***
					(0.003)
Years of schooling					0.061***
					(0.016)
Per capita physical capital					0.297***
					(0.018)
Per hectare grain output					0.142***
					(0.023)
Panel B: Mediation effects calculated					
	Crude birth rate	Years of schooling	Per capita physical capital	Per hectare grain output	Total
Mediation effect	−0.028***	−0.017***	−0.022***	−0.023***	−0.091***
	(0.008)	(0.005)	(0.010)	(0.005)	(0.015)
Share of the effect mediated, %	25.2	15.3	19.8	20.7	81.9

Notes: This table reports the estimation results of model (10) that instruments grain imports in each equation by the Bartik IV. Panel A reports the estimated coefficients: column 1–4 report $\hat{a}_k$, and column 5 reports $\hat{b}_k$ and $\hat{c}$. Panel B reports the calculated mediation effect of each variable ($\hat{a}_k \times \hat{b}_k$) in columns 1–4 and the total mediation effect ($\sum_k \hat{a}_k \times \hat{b}_k$) in column 5. Significance levels are $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

be explained by variables characterizing these channels. I measure agriculture output by per hectare grain output, measure manufacturing output by per capita physical capital,[21] measure population growth by the crude birth rate, and measure human capital formation by years of total schooling.[22]

The mediation analysis involves estimating a system of equations:

$$\begin{aligned}
m^1_{it} &= \upsilon_i + \tau_t + a_1 \ln I_{it} + \mu^1_{it} \\
m^2_{it} &= \upsilon_i + \tau_t + a_2 \ln I_{it} + \mu^2_{it} \\
&\;\vdots \\
m^K_{it} &= \upsilon_i + \tau_t + a_K \ln I_{it} + \mu^K_{it} \\
\ln y_{it} &= \upsilon_i + \tau_t + c \ln I_{it} + \sum_{k=1}^{K} b_k m^k_{it} + \mu_{it}.
\end{aligned} \tag{10}$$

The first K equations estimate the effect of grain imports ($\ln I_{it}$) on each of the K mediator variables (m^k_{it}), and the last equation estimates the effect of grain imports on GDP per capita ($\ln y_{it}$) conditional on mediator variables. All equations include the country- and year-fixed effects and use the Bartik IV to address the endogeneity of grain imports. The coefficient a_k captures the causal effect of grain imports on mediator k, b_k captures the association between mediator k and GDP per capita, and c captures the remaining effect of grain imports that are not mediated. Therefore, the mediation effect through each mediator is $a_k \times b_k$, and the share of the effect mediated by each mediator is $\frac{a_k \times b_k}{\beta_1}$, where β_1 is the 2SLS estimate of the coefficient of grain imports from model (6).

Table 5 reports the estimation results. According to columns 1–4 of Panel A, the estimated effects of grain imports on the four mediators ($\hat{a}_k$) are all statistically significant and consistent with the prediction. Specifically, the estimates indicate that grain imports increased fertility, reduced human capital formation, and reduced agricultural and manufacturing outputs. Column 5 of Panel A presents the estimated effect of each mediator on income ($\hat{b}_k$) and the remaining effect of grain imports ($\hat{c}$). All mediators have significant effects on income, and the remaining effect of grain imports is only −0.015. Panel B reports the calculated mediation effect of each mediator ($\hat{a}_k \times \hat{b}_k$) and the percentage of the total effect explained by each mediator ($\frac{\hat{a}_k \times \hat{b}_k}{\hat{\beta}_1} \times 100$). The four mediator variables, respectively, explained 25.2%, 15.3%, 19.8%, and 20.7% of the effect of grain imports on GDP per capita, and these four variables together explained 81.9% of the effect.

The explanatory power of each mediator should be interpreted with caution, as the mediators might be endogenous and correlated. While grain imports in each equation of model (10) are instrumented by the Bartik IV, providing independent instruments for mediators is difficult. As such, the estimate $\hat{b}_k$ merely reflects an associative relationship. Nevertheless, the mechanisms identified

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[21] While it is straightforward to show that grain imports reduced per capita output in agriculture and manufacturing (see columns 5 and 6 of Table 4), it is trivial to examine the mediation effect of sectoral output on total output.

[22] I have also tried to examine the mediation effects of various other factors, such as death rate, life expectancy, dependency ratio, urbanization rate, and foreign direct investment, and found that they have negligible explanatory power on the damage of grain imports.

(based on the IV estimates in columns 1–4 of Panel A) and the total mediation effect calculated (based on the IV estimates $\hat{\beta}_1$ and $\hat{c}$, i.e., $\frac{(\hat{\beta}_1-\hat{c})}{\hat{\beta}_1} = 81.9\%$) are reasonably credible.

6. Effects on income divergence

This section evaluates the extent to which the GR can explain the income divergence observed between the 75 developing countries since the 1960s. As discussed above, the GR affected a country's income per capita through two major channels: the direct effect through domestic HYV adoption (estimated by Gollin et al. 2021) and the indirect effect through grain trade (estimated in this article). I combine the direct and indirect effects to evaluate the total effect of the GR on cross-country income divergence.

Panel A of Fig. 11 presents the estimated indirect effect of the GR on GDP per capita by 2000 for each of the 75 developing countries. The country-level indirect effect is calculated by combining each country's RDA in 2000, the marginal effect of RDA on grain imports (column 4 of Table 2), and the marginal effect of grain imports on GDP per capita (column 2 of Table 3). I calculate the impact as the percentage of the GDP per capita in 2000.[23] Only 12 countries (mainly from Asia and South America) benefited from GR-induced grain trade, whereas the remaining 63 countries were damaged. This finding is consistent with the observation that several large countries (e.g., China and India) dominated the cultivation areas of HYVs in the developing world. The average effect of GR-induced grain trade across the 75 countries was −25.7% (of the 2000 GDP per capita), with a standard deviation of 26.5%.

Panel B of Fig. 11 presents the direct effect, estimated closely following Gollin et al. (2021):

$$\ln y_{it} = \upsilon_i + \tau_t + \gamma_1 HYV_{it} + Z_{it}\lambda + \mu_{it}, \tag{11}$$

where HYV_{it} is the adoption rate of HYV in country i and year t, and all other variables are the same as defined before. The endogeneity of HYV_{it} is addressed using two IVs similar to those for RDA: the predicted HYV adoption rate calculated in equation (13) and the predicted GR calculated in equation (15). The estimation results are reported in Table A.7. The 2SLS estimate of γ_1 suggests that a 1% increase in the HYV adoption rate leads to a 1.66 percentage points increase in the GDP per capita. As detailed in Appendix F, this estimate is close to those from Gollin et al. (2021). I combine this estimate with the HYV adoption rate in 2000 to calculate the country-level direct effect (measured again as the percentage of the 2000 GDP per capita). The results show that most countries directly benefited from the HYV adoption, but the gains differed widely across countries: while many Asian countries had gains over 50%, the gains for African countries were generally limited. The direct effect of the GR increased the (simple) average GDP per capita of the 75 countries by 27.2%, with a standard deviation of 24.8%.

Panel C presents the total effect, calculated as the sum of the direct and indirect effects. It shows that the GR increased the GDP per capita in 37 countries, while it reduced it in the remaining 38 countries. The average gain of the benefited countries was 35.3% of 2000 GDP per capita, while the average loss of the damaged countries was 31.4%. The simple average effect across the 75 countries was close to zero (1.5%).[24] Countries that experienced the largest loss were from Africa, whereas those that gained the most were from Asia. Twelve African countries experienced losses greater than 30% (Burundi, Central African Republic, Chad, Congo, Liberia, Malawi, Mauritania, Niger, Senegal, South Africa, Togo, Zambia), while 11 Asian countries experienced gains over 30% (Bangladesh, China, India, Indonesia, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Vietnam). Note that not only African countries were damaged; other countries that experienced losses greater than 10% were from the Latin America and the Caribbean (Panama, Jamaica, Honduras, Nicaragua, Haiti, Bolivia, El Salvador, and Guatemala), the Middle East and North Africa (Yemen, Jordan, and Sudan), and Asia (Cambodia and Mongolia).

Fig. 12 illustrates the extent to which the income divergence observed between the benefited and damaged countries can be explained by the estimated total effect of the GR. I classify the 75 sample countries into two groups based on whether the total effect of the GR on their GDP per capita by 2000 was positive (37 countries) or negative (38 countries). I then compare the actual GDP per capita (solid lines) of the two groups with the corresponding counterfactual GDP per capita (dashed lines), which eliminates the total effect of the GR.[25] The actual difference in GDP per capita (in 2011 US$) between these two group of countries increased from 198 US$ in 1965 to 3322 US$ in 2000. However, when the effect of the GR is removed (i.e., the dashed lines), these two groups are roughly parallel in GDP per capita throughout the sample period. Therefore, the GR is a major cause of the income divergence observed between these two groups of developing countries from 1965 to 2000.

Fig. 13 presents an even more intuitive exercise to illustrate the GR's explanatory power for income divergence. It shows that the significantly negative correlation between changes in RDA and changes in log GDP per capita from 1965 to 2000 across the 75 countries was mainly driven by the GR. Panel A indicates that changes in RDA and changes in log GDP per capita were negatively

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[23] I first combine country-level RDA in 2000 with the marginal effect of RDA on grain imports to estimate the percentage effect of the GR on grain imports by 2000. I then combine the resulting estimate with the marginal effect of grain imports on GDP per capita to calculate the percentage effect of the GR on GDP per capita through grain trade by 2000. Note that this estimated percentage effect is relative to the GDP per capita in 1960, the year before the GR starting in 1965 (recall that I use five-year interval data). To facilitate interpretation, I transformed the estimate to the percentage of the 2000 GDP per capita by multiplying it by the ratio of the 1960 GDP per capita to the 2000 GDP per capita.

[24] The population-weighted average is significantly positive (45.8%) because some large countries, such as China and India, benefited substantially.

[25] The counterfactual GDP per capita (income for short) for each group in a given year, such as 1990, is calculated in three steps. First, I multiply a country's 1960 income by the estimated percentage effect by 1990 to obtain the changes in income from 1960 to 1990 that were caused by the GR. Second, I subtract the GR's effect calculated in the first step from the observed 1990 income to obtain the counterfactual income in 1990 for each country. Finally, I calculate the average counterfactual income across countries in each group.

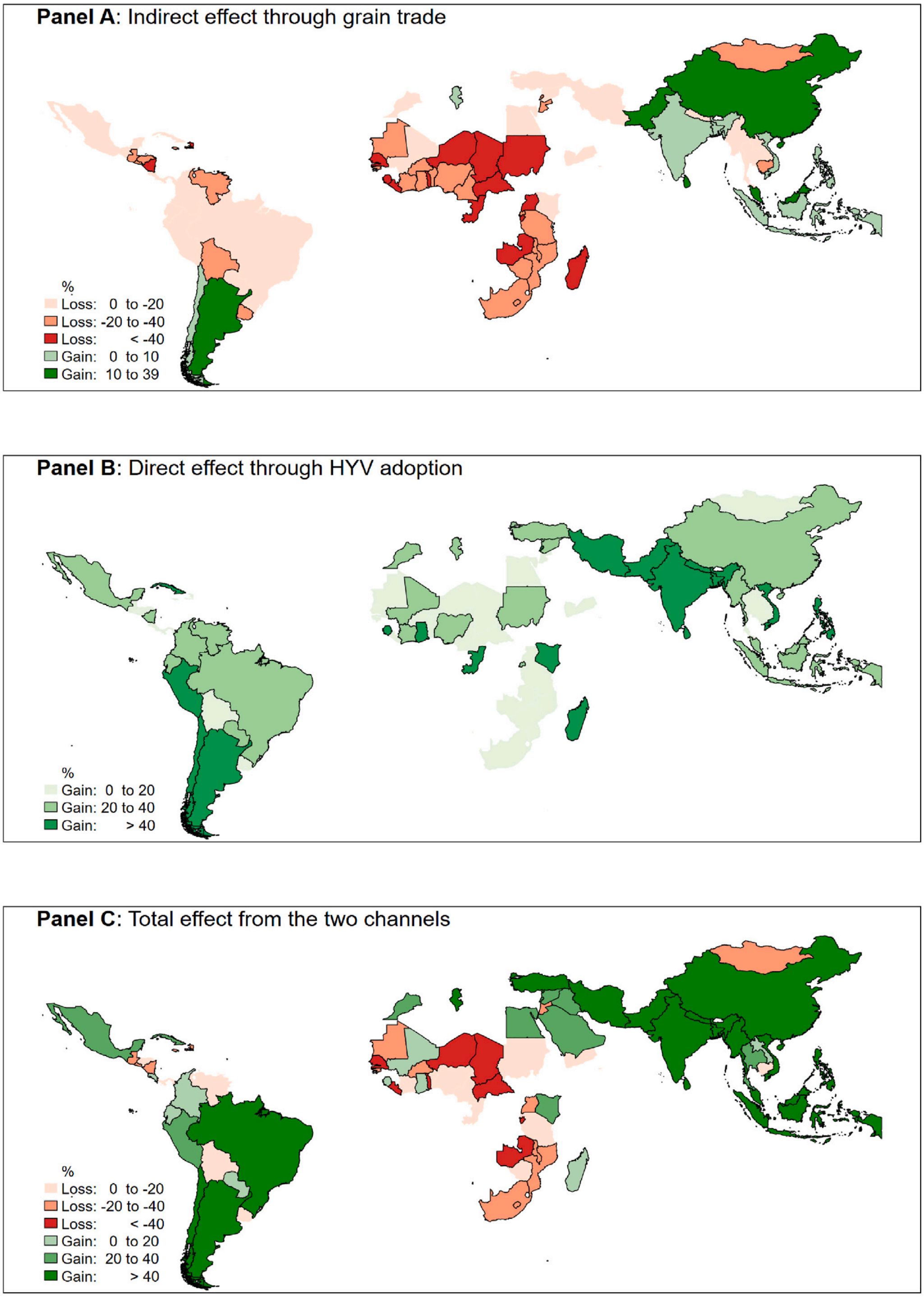

Fig. 11. Impact of the GR on GDP per capita through the two channels.

Notes: Panel A presents the indirect effect of the GR through grain trade, panel B presents the direct effect of the GR through domestic HYV adoption, and panel C presents the total effect calculated as the sum of the direct and indirect effects.

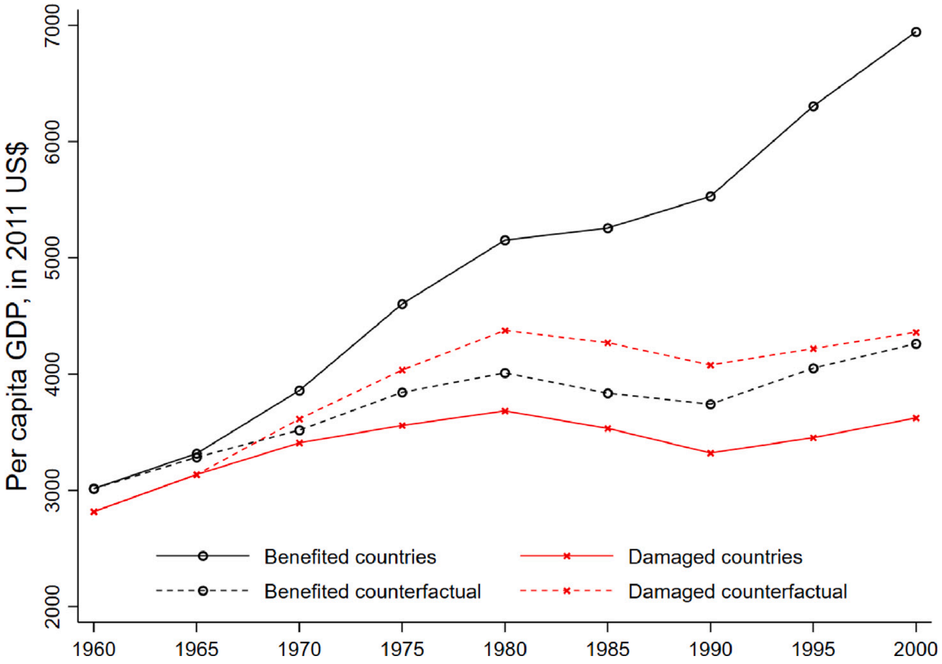

Fig. 12. Explanatory power of the GR for income divergence.
Notes: The figure classifies the 75 developing countries into two groups based on whether the total effect of the GR on their GDP per capita by 2000 was positive (37 countries) or negative (38 countries). The solid lines represent the observed GDP per capita, and the dashed lines represent the counterfactual GDP per capita, which eliminates the estimated total effect of the GR (See Footnote for details of the calculation).

and strongly correlated and that some developing countries with a large RDA (mainly African countries) experienced a substantial decline in GDP per capita. In Panel B, when the indirect effect is removed, the negative correlation becomes weaker, and the income declines observed in African countries disappear. In Panel C, the negative correlation almost vanishes when both the indirect and direct effects are removed. Therefore, without the GR, Asian countries in the sample would have experienced no faster growth, on average, than African countries.

7. A comparison with the literature

7.1. *The study of Gollin, Hansen, and Wingender (2021)*

The study of Gollin et al. (2021) (GHW) shows that developing countries more suitable for cultivating GR crops experienced faster growth in crop yields and GDP per capita after the GR.[26] My study is closely related to GHW in three aspects. First, both studies examine the economic impact of the GR based on similar data sets. Second, this study follows GHW to employ exogenous variation in the timing of the GR and the agro-climatic suitability for cultivating GR crops when estimating the effect of the GR on grain imports. Third, both studies find a positive link between the adoption rate of HYVs and economic performance. However, this study is fundamentally different from GHW in its focus and the implications of the findings.

This study focuses on examining the effect of the GR through grain trade, while GHW focuses on examining the effect of domestic GR on domestic economic outcomes. Motivated by the fact that countries disadvantaged in adopting HYVs experienced dramatic increases in grain imports, this study attempts to estimate the impact of GR-induced grain imports in two steps. I first estimate the effect of the GR on grain imports by employing two IVs constructed based on the agro-climatic suitability for cultivating the GR crops and on the different timing of the GR across crops. I then estimate the effect of GR-induced grain imports on domestic GDP per capita by employing a Bartik IV constructed based on exogenous grain supply shocks and the bilateral distance to grain exporters. In contrast, GHW directly estimate the effect of domestic GR on domestic economic performances based on the same exogenous variation employed in the first step of this study.

The differences in the target of the study and the identification strategy determine that the implications of the estimates are fundamentally different, although both studies identified a positive causal link between the GR and economic growth. Briefly, the positive link in this study is driven by the damage of GR-induced grain imports on countries disadvantaged in adopting HYVs, while

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[26] The finding of GHW is in line with micro-level evidence from developing countries showing that high world prices of food are, in general, bad for the world's poor (e.g., Ivanic and Martin, 2008).

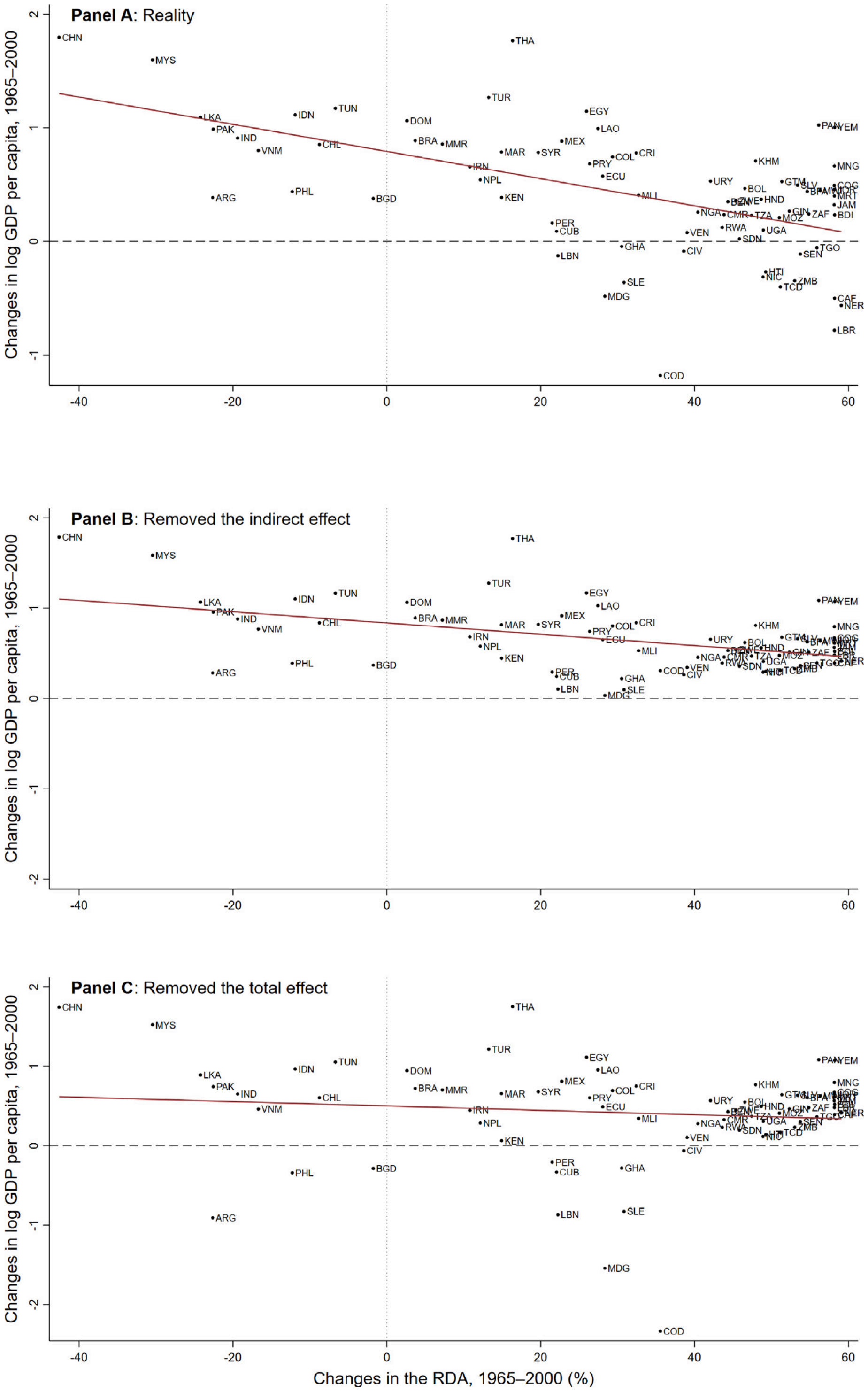

Fig. 13. Changes in log GDP per capita and RDA from 1965 to 2000.

Notes: Panel A presents the correlation between changes in log GDP per capita and RDA from 1965 to 2000 across the 75 developing countries. Panel B removes the indirect effect of the GR from Panel A, and Panel C removes the direct effect of the GR from Panel B.

the positive link in GHW is driven by the benefits of domestic adoption of HYVs. In other words, the positive link in this study reflects that countries that import more grain following the GR are more seriously damaged, while the positive link in GHW reflects that countries that adopt more HYVs benefit more. This difference is most clear when focusing on countries that adopted no HYVs; these countries are most seriously damaged according to the estimate of this study but are unaffected according to the estimate of GHW. Panels A and B of Fig. 11 present the country-level differences in the estimated effects based on these two studies.

More specifically, although both studies depend on comparing countries with different adoption rates of HYVs, the two-step process of estimation in this study ensures that the estimate of this study reflects the damage of GR-induced grain imports instead of the benefits from domestic HYV adoption. As detailed in Section 5.2, the Bartik IV employed in the second step of the estimation helps exclude the confounding effect of domestic HYV adoption because foreign grain supply shocks are not directly correlated with the domestic HYV adoption rate of individual developing countries. I also show that the estimate in this study is not primarily driven by the benefits of GR-advantaged countries from exporting grains; a comparable estimate is obtained when net grain importing countries are excluded from the estimation (column 1 of Table 4).

7.2. The prediction of CGE models

This study is closely linked to a vast body of literature that utilizes Computable General Equilibrium (CGE) models to assess the welfare impact of agricultural production shocks. For instance, numerous studies have employed the GTAP (Global Trade Analysis Project) model to analyze how agricultural production shocks feed through the global economy (e.g., Anderson and Tyers, 1993; Anderson et al., 2001; Anderson, 2004; Anderson et al., 2005). Similarly, there exists literature focused on developing countries that employs IFPRI's IMPACT model (the International Model for Policy Analysis of Agricultural Commodities and Trade) to examine the effects of agricultural production changes (e.g., Agcaoili-Sombilla and Rosegrant, 1994; Arndt et al., 2005; Wiebe et al., 2021, 2022).[27] Contrary to the findings of this study, prior studies utilizing CGE models typically predict that positive supply shocks in agriculture for grain-exporting countries yield welfare gains for net grain-importing countries.

A crucial distinction between this study and previous model-based literature is that this study does not rely on strong assumptions to infer the impact of grain imports. Both the GTAP and IMPACT models depend on assumptions of perfect competition and constant returns to scale. Moreover, to implement the complex CGE model, modelers must make heroic assumptions about the elasticity of demand and supply for agricultural commodities, as well as the interaction between the local economy and the broader surrounding economy. These strong assumptions can potentially limit the ability to capture the true impact of grain imports. For example, the assumption of constant returns to scale in CGE models restricts their capacity to capture the detrimental effects of grain imports on manufacturing growth through learning-by-doing, which represents a source of increasing returns to scale essential for explaining the damages caused by grain imports (see Appendix A for additional details). Conversely, this study identifies the causal effect of grain imports by employing plausible exogenous IVs and is able to more flexibly and transparently capture the overall impact of grain imports on economic outcomes.

7.3. The theory of Matsuyama (1992)

Matsuyama (1992) examines the consequences of high agricultural productivity on development pathways within a two-sector framework. According to his analysis, the outcomes differ between open and closed economies. In an open economy, high agricultural productivity promotes structural change. Conversely, in a closed economy, a small open economy that specializes in agricultural production due to its comparative advantage may miss out on the growth opportunities that a less agriculture-focused economy would enjoy. Matsuyama's model assumes that the non-agricultural sector benefits from learning-by-doing. As a result, a small open economy with a comparative advantage in agriculture would not experience the same level of growth as a less agricultural economy. Therefore, Matsuyama's (1992) model predicts the opposite impact of grain imports on the economic outcome of an open economy compared to the prediction derived from the conceptual framework of this study.

As detailed in Appendix A, the conceptual framework of this study is closely related to that of Matsuyama (1992) in the sense that both are based on the assumptions of learning-by-doing in manufacturing and Engel's law in food consumption. However, the conceptual framework of this study arrives at the opposite prediction for two reasons: first, it assumes the existence of a third extractive sector that has low growth potential; second, it incorporates the observation that countries disadvantaged in agriculture also have no comparative advantage in manufacturing (see Section 2.5 for evidence). The conceptual framework of this study would have the same prediction as that of Matsuyama (1992) if countries disadvantaged during the GR have a comparative advantage in manufacturing.

8. Concluding remarks

This study finds that the GR can largely explain the income divergence observed across developing countries since the 1960s. It shows that without the GR, Asian developing countries would have experienced no faster growth, on average, than African countries.

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[27] Both GTAP and IMPACT are specific types of CGE models (Mitra-Kahn, 2008).

Existing studies generally explain cross-country income divergence by non-agricultural factors, such as institutions facilitating the protection of property rights, various geographical factors, human capital, and international trade of non-agricultural goods. This study supplements the literature and highlights the central role of cross-country differences in agricultural growth in global income divergence.

Beyond the conventional understanding that domestic agricultural growth promotes domestic income growth, this study shows that a disadvantage in agriculture (relative to foreign countries) hinders the growth of developing countries by increasing their grain imports. A stylized observation is that countries that have experienced more agricultural growth have better subsequent economic performances. This observation is usually interpreted as a positive effect of domestic agricultural growth on domestic economic growth. However, this study provides causal evidence showing that this positive link could also be driven by the damage of foreign agricultural growth to domestic economic growth through international trade.

I highlight that the findings of this article do not necessarily suggest that the GR leads to net welfare loss in GR-disadvantaged countries. The main analysis focuses on per capita income, which is only one dimension of human well-being. In Appendix Tables A.8, I further show that the GR-caused grain imports also deteriorate other welfare measures: per capita consumption, per capita household consumption, life expectancy, infant mortality, and poverty rate. However, a major driving force of these per capita welfare impacts is the population expansion caused by the GR. Therefore, the welfare implications of the GR for these countries depend on how we think about the welfare of people who are alive in one scenario but might not have ever been born in another.

I conclude by highlighting three additional limitations of this study. Firstly, due to a lack of early micro data, this study is unable to examine the distributional effect of the GR across different income groups within a developing country. If poverty alleviation is a more crucial target than average economic growth, the impact of the GR on GR-disadvantaged countries could be more positive, as lower food prices should have contributed to poverty reduction. Secondly, the findings of this study are only applicable to the average developing country in the sample. As emphasized in the conceptual framework, developing countries with a comparative advantage in manufacturing may not have been adversely affected by grain imports. Finally, this study relies solely on HYV adoption data prior to 2000, while significant efforts have been made to enhance the productivity of other crop varieties since the late 1990s. Consequently, the findings of this study may have limited implications for the economic development of GR-disadvantaged countries after 2000.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.euroecorev.2024.104772.

References

Acemoglu, Daron, 2009. Introduction to modern economic growth. Princeton University Press, Princeton, NJ.

Acemoglu, Daron, Naidu, Suresh, Restrepo, Pascual, Robinson, James A., 2019. Democracy does cause growth. J. Polit. Econ. 127 (1), 47–100.

Adamopoulos, Tasso, Restuccia, Diego, 2021. Geography and agricultural productivity: Cross-country evidence from micro plot-level data. Rev. Econ. Stud. (ISSN: 0034-6527) 1629–1653.

Adao, Rodrigo, Kolesár, Michal, Morales, Eduardo, 2019. Shift-share designs: Theory and inference. Q. J. Econ. (ISSN: 0033-5533) 134 (4), 1949–2010.

Agcaoili-Sombilla, Mercedita C., Rosegrant, Mark W., 1994. International trade in a differentiated good: Trade elasticities in the world rice market. Agric. Econ. 10 (3), 257–267.

Allen, Robert C., 2011. Global economic history: a very short introduction, vol. 282, Oxford University Press, Oxford, England, ISBN: 0199596654.

Andersen, Thomas Barnebeck, Jensen, Peter Sandholt, Skovsgaard, Christian Volmar, 2016. The heavy plow and the agricultural revolution in medieval europe. J. Dev. Econ. (ISSN: 0304-3878) 118, 133–149.

Anderson, Kym, 2004. Agricultural trade reform and poverty reduction in developing countries, vol. 3396, World Bank Publications.

Anderson, Kym, Dimaranan, Betina, Francois, Joe, Hertel, Tom, Hoekman, Bernard, Martin, Will, 2001. The cost of rich (and poor) country protection to developing countries. J. African Econ. 10 (3), 227–257.

Anderson, Kym, Jackson, Lee Ann, Nielsen, Chantal Pohl, 2005. Genetically modified rice adoption: implications for welfare and poverty alleviation. J. Econ. Integr. 771–788.

Anderson, Kym, Tyers, Rod, 1993. More on welfare gains to developing countries from liberalizing world food trade. J. Agric. Econ. 44 (2), 189–204.

Arndt, Channing, et al., 2005. The Doha trade round and Mozambique. World Bank.

Ashraf, Quamrul, Michalopoulos, Stelios, 2015. Climatic fluctuations and the diffusion of agriculture. Rev. Econ. Stat. 97 (3), 589–609.

Baron, R.M., Kenny, D.A., 1986. The moderator-mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. J. Personal. Soc. Psychol. (ISSN: 0022-3514 (Print) 0022-3514) 51 (6), 1173–1182. http://dx.doi.org/10.1037//0022-3514.51.6.1173.

Barro, Robert J., Sala-i Martin, Xavier, 2004. Economic Growth, second ed. The MIT Press, Cambridge, Massachusetts.

Becker, Gary S., Lewis, H. Gregg, 1973. On the interaction between the quantity and quality of children. J. Polit. Econ. (ISSN: 0022-3808) 81 (2, Part 2), S279–S288.

Becker, Gary S., Murphy, Kevin M., Tamura, Robert, 1990. Human capital, fertility, and economie growth. J. Polit. Econ. 98 (5), S12–S37.

Ben-David, Dan, 1993. Equalizing exchange: Trade liberalization and income convergence. Q. J. Econ. (ISSN: 1531-4650) 108 (3), 653–679.

Borusyak, Kirill, Hull, Peter, Jaravel, Xavier, 2022. Quasi-experimental shift-share research designs. Rev. Econ. Stud. 89 (1), 181–213.

Bustos, Paula, Caprettini, Bruno, Ponticelli, Jacopo, 2016. Agricultural productivity and structural transformation: Evidence from Brazil. Am. Econ. Rev. 106 (6), 1320–1365.

Cameron, A. Colin, Gelbach, Jonah B., Miller, Douglas L., 2008. Bootstrap-based improvements for inference with clustered errors. Rev. Econ. Stat. 90 (3), 414–427.

Carillo, Mario F., 2021. Agricultural policy and long-run development: Evidence from mussolini's battle for grain. Econ. J. (ISSN: 0013-0133) 131 (634), 566–597.

Conway, Gordon, 2012. One billion hungry: Can we feed the world?. Cornell University Press, New York, United States, ISBN: 0801466083.

Costinot, Arnaud, Donaldson, Dave, 2012. Ricardo's theory of comparative advantage: Old idea, new evidence. Amer. Econ. Rev. 102 (3), 453–458.

Dall Schmidt, Torben, Jensen, Peter Sandholt, Naz, Amber, 2018. Agricultural productivity and economic development: the contribution of clover to structural transformation in Denmark. J. Econ. Growth (ISSN: 1573-7020) 23 (4), 387–426.

Evenson, Robert E., 2005. Besting malthus: the green revolution. Proc. Am. Philos. Soc. (ISSN: 0003-049X) 149 (4), 469–486.

Evenson, Robert E., Gollin, Douglas, 2003a. Crop variety improvement and its effect on productivity: The impact of international agricultural research. CABI Publishing, Cambridge, MA.

Evenson, Robert E., Gollin, Douglas, 2003b. Assessing the impact of the green revolution, 1960 to 2000. Science (ISSN: 0036-8075) 300 (5620), 758–762.

FAO, 2000. Trade liberalization and food security: Conceptual links. In: Trade Reform and Food Security, FAO Document, Rome.

Feyrer, James, 2019. Trade and income—exploiting time series in geography. Am. Econ. J. Appl. Econ. (ISSN: 1945-7782) 11 (4), 1–35.

Foster, Andrew D., Rosenzweig, Mark R., 1995. Learning by doing and learning from others: Human capital and technical change in agriculture. J. Political Econ. 103 (6), 1176–1209.

Foster, Andrew D., Rosenzweig, Mark R., 1996. Technical change and human-capital returns and investments: evidence from the green revolution. Amer. Econ. Rev. (ISSN: 0002-8282) 931–953.

Foster, Andrew D., Rosenzweig, Mark R., 2004. Technological change and the distribution of schooling: evidence from green-revolution India. J. Dev. Econ. (ISSN: 0304-3878) 74 (1), 87–111.

Frankel, Jeffrey A., Romer, David H., 1999. Does trade cause growth? Am. Econ. Eeview (ISSN: 0002-8282) 89 (3), 379–399.

Galor, Oded, Mountford, Andrew, 2006. Trade and the great divergence: the family connection. Am. Econ. Rev. (ISSN: 0002-8282) 96 (2), 299–303.

Galor, Oded, Mountford, Andrew, 2008. Trading population for productivity: theory and evidence. Rev. Econ. Stud. (ISSN: 1467-937X) 75 (4), 1143–1179.

Galor, Oded, Tsiddon, Daniel, 1997. The distribution of human capital and economic growth. J. Econ. Growth 2 (1), 93–124.

Gollin, Douglas, Hansen, Casper Worm, Wingender, Asger Mose, 2021. Two blades of grass: The impact of the green revolution. J. Polit. Econ. (ISSN: 0022-3808) 129 (8).

Gollin, Douglas, Lagakos, David, Waugh, Michael E., 2014. Agricultural productivity differences across countries. Amer. Econ. Rev. 104 (5), 165–170.

Gollin, Douglas, Parente, Stephen, Rogerson, Richard, 2002. The role of agriculture in development. Amer. Econ. Rev. (ISSN: 0002-8282) 92 (2), 160–164.

Greenstone, Michael, Mas, Alexandre, Nguyen, Hoai-Luu, 2020. Do credit market shocks affect the real economy? Quasi-experimental evidence from the great recession and "normal" economic times. Am. Econ. J. Econ. Policy 12 (1), 200–225.

Grossman, Gene M., Helpman, Elhanan, 1991. Quality ladders in the theory of growth. Rev. Econ. Stud. (ISSN: 1467-937X) 58 (1), 43–61.

Hart, Gillian, 1998. Regional linkages in the era of liberalization: A critique of the new agrarian optimism. Dev. Change (ISSN: 0012-155X) 29 (1), 27–54.

Hazell, Peter B.R., 2009. The Asian green revolution. International Food Policy Research Institute, Washington, DC.

Hazell, Peter B.R., 2010. Proven successes in agricultural development. International Food Policy Research Institute, Washington, DC, pp. 67–97.

Howitt, Peter, 1999. Steady endogenous growth with population and R&D inputs growing. J. Polit. Econ. (ISSN: 0022-3808) 107 (4), 715–730.

Huang, kaixing, Guo, Jingyuan, Zhao, Da, 2023. Positive rainfall shocks, overoptimism, and agricultural inefficiency in China. J. Assoc. Environ. Resour. Econ. (ja), null. http://dx.doi.org/10.1086/727761.

Ivanic, Maros, Martin, Will, 2008. Implications of higher global food prices for poverty in low-income countries 1. Agric. Econ. 39, 405–416.

Jones, Eric, 1981. The European miracle: environments, economies and geopolitics in the history of Europe and Asia. Cambridge University Press, Cambridge, UK, ISBN: 052152783X.

Jones, Charles I., 1995. R&D-based models of economic growth. J. Polit. Econ. (ISSN: 0022-3808) 759–784.

Jones, Peter M., 2016. Agricultural enlightenment: knowledge, technology, and nature, 1750-1840. Oxford University Press, Oxford, England, ISBN: 0191025151.

Kopsidis, Michael, Wolf, Nikolaus, 2012. Agricultural productivity across prussia during the industrial revolution: A thünen perspective. J. Econ. History (ISSN: 0022-0507) 634–670.

Krugman, Paul, Venables, Anthony J., 1995. Globalization and the inequality of nations. Q. J. Econ. (ISSN: 1531-4650) 110 (4), 857–880.

MacKinnon, David P., 2012. Introduction to statistical mediation analysis. Routledge.

Malthus, Thomas Robert, 1798. An essay on the principle of population, vol. 1, Pickering & Chatto Publishers, London, pp. 1–139.

Matsuyama, Kiminori, 1992. Agricultural productivity, comparative advantage, and economic growth. J. Econom. Theory (ISSN: 0022-0531) 58 (2), 317–334.

Mayer, Thierry, Zignago, Soledad, 2011. Notes on cepii's distances measures: The GeoDist database. CEPII Working Paper 2011-25.

McCalla, Alex F., 2001. What the developing countries want from the WTO. Estey J. Int. Law Trade Policy 2 (1753-2016-141116), 165–177.

Miller, Steve, Chua, Kenn, Coggins, Jay, Mohtadi, Hamid, 2021. Heat waves, climate change, and economic output. J. Eur. Econom. Assoc. 19 (5), 2658–2694.

Mitra-Kahn, Benjamin Hav, 2008. Debunking the myths of computable general equilibrium models. URL https://api.semanticscholar.org/CorpusID:154621468.

Mokyr, Joel, 2001. The gifts of Athena: Historical origins of the knowledge economy. Princeton University Press, Princeton, NJ.

Mokyr, Joel, 2011. The enlightened economy: Britain and the industrial revolution, 1700-1850. Penguin UK, London, England, ISBN: 0140278176.

Moscona, Jacob, 2019. Agricultural development and structural change within and across countries. Tech. rep, Mimeo, MIT.

Nunn, Nathan, Qian, Nancy, 2011. The potato's contribution to population and urbanization: Evidence from a historical experiment. Q. J. Econ. (ISSN: 1531-4650) 126 (2), 593–650.

Overton, Mark, 1996. Agricultural revolution in England: The transformation of the agrarian economy 1500-1850. Cambridge University Press, Cambridge, England, ISBN: 0521568595.

Pingali, Prabhu L., 2012. Green revolution: Impacts, limits, and the path ahead. Proc. Natl. Acad. Sci. (ISSN: 0027-8424) 109 (31), 12302–12308.

Pomeranz, Kenneth, 2000. The Great Divergence: China, Europe, and the making of the modern world economy. Princeton University Press, ISBN: 1400823498.

Renkow, Mitch, Byerlee, Derek, 2010. The impacts of CGIAR research: A review of recent evidence. Food Policy (ISSN: 0306-9192) 35 (5), 391–402.

Restuccia, Diego, Yang, Dennis Tao, Zhu, Xiaodong, 2008. Agriculture and aggregate productivity: A quantitative cross-country analysis. J. Monetary Econ. (ISSN: 0304-3932) 55 (2), 234–250.

Ricardo, David, 1821. On the principles of political economy. J. Murray London.

Rodriguez, Francisco, Rodrik, Dani, 2000. Trade policy and economic growth: a skeptic's guide to the cross-national evidence. NBER Macroecon. Ann. (ISSN: 0889-3365) 15, 261–325.

Romer, Paul M., 1990. Endogenous technological change. J. Polit. Econ. (ISSN: 0022-3808) S71–S102.

Strulik, Holger, Weisdorf, Jacob, 2008. Population, food, and knowledge: a simple unified growth theory. J. Econ. Growth 195–216.

Vollrath, Dietrich, 2011. The agricultural basis of comparative development. J. Econ. Growth (ISSN: 1381-4338) 16 (4), 343–370.

Wiebe, Keith, Sulser, Timothy B., Dunston, Shahnila, Robertson, Richard, Rosegrant, Mark, Willenbockel, Dirk, 2022. Modeling biophysical and socioeconomic interactions in food systems with the international model for policy analysis of agricultural commodities and trade (IMPACT). In: Food Systems Modelling. Elsevier, pp. 213–230.

Wiebe, Keith, Sulser, Timothy B., Dunston, Shahnila, Rosegrant, Mark W., Fuglie, Keith, Willenbockel, Dirk, Nelson, Gerald C., 2021. Modeling impacts of faster productivity growth to inform the cgiar initiative on crops to end hunger. PLoS One 16 (4), e0249994.

WorldBank, 2007. Agriculture for development. The International Bank for Reconstruction and Development, Washington, DC.

Young, Alwyn, 1991. Learning by doing and the dynamic effects of international trade. Q. J. Econ. (ISSN: 1531-4650) 106 (2), 369–405.