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North–South trade and directed technical change ☆

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ABSTRACT

In a world where poor countries provide weak protection for intellectual property rights (IPRs), market integration shifts technical change in favor of rich nations. Through this channel, free-trade may amplify international wage differences. At the same time, integration with countries where IPRs are weakly protected can slow down the world growth rate. An important implication of these results is that protection of intellectual property is most beneficial in open countries. This prediction, which is novel in the literature, is consistent with evidence from a panel of 53 countries observed in the years 1965–1990. The paper also provides empirical support for the mechanism linking North–South trade to the direction of technical change: an increase in import penetration from low-wage, low-IPRs countries is followed by a sharp fall in R&D investment in a panel of US manufacturing sectors.

1. Introduction

The past decades have witnessed a dramatic rise in the degree of economic integration across the globe. A notable feature of this phenomenon is the emerging role played by less developed countries (LDCs) in world markets. Although trade between the US and non-OECD countries is still relatively small, its share in US GDP increased by more than fourfold between 1970 and 1995. In the same years, unprecedented episodes of economic liberalization took place in countries like China, Mexico and India. As a result, North–South trade is now the fastest growing component of world trade. This process of international integration has been accompanied by concerns regarding the economic losses due to weak protection of intellectual property rights (IPRs) in less developed countries. The issue has become one of the most debated in international negotiations and led to the inclusion of the Agreement on Trade Related

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Intellectual Property Rights (TRIPS) in the statute of the WTO in 1994.[1] After more than 10 years, the extent to which LDCs should protect intellectual property is still controversial. Moreover, despite the close connection between IPRs and trade negotiations, the relationship between market integration and the protection of intellectual property remains largely unclear.

This paper studies how North–South trade affects the direction of technical progress, growth and wage differences in a model where less developed countries provide weak protection for intellectual property. Although it does not address the question of how to design an optimal system of international IPRs regulations, it shows that the effect of trade opening on growth and relative wages depends crucially on the degree of protection of intellectual property worldwide. In particular, whenever poor countries do not provide adequate protection for IPRs, North–South trade shifts the direction of technical change in favor of rich nations. By making the sectors in which poor countries are specialized relatively less productive, trade may thus amplify North–South wage differences. Moreover, the paper shows that integration of product markets with countries where intellectual property rights are weakly protected may lower the incentives to innovate and economic growth, even if the market for technology remains unchanged.

To obtain these results, the paper builds a Ricardian model with a continuum of goods and endogenous, sector-specific (directed), technical change. It describes a world economy composed by two sets of countries, the North and the South, distinguished by an exogenous pattern of comparative advantage. Except for these Ricardian differences and given that nowadays barriers to the flow of ideas are low, all countries have access to the same stock of technical knowledge, that can be expanded by investing in innovation. As in R&D-driven models of endogenous growth, innovation is financed by the monopoly rents it generates. However, the key assumption of the paper is that innovators can only appropriate a fraction of the rents from the Southern markets because of weak protection of IPRs.

The model is solved both in autarky and free-trade and the equilibria are compared. In both cases, the equilibrium has a number of desirable properties: the world income distribution is stable, growth rates are equalized across sectors, and countries with higher exogenous productivity levels are relatively richer. But the North–South wage gap depends crucially on the trade regime. Without trade in goods, each country produces in all sectors and the South can free ride on innovation performed for the Northern markets. Under free-trade, instead, the two countries specialize in the sectors of comparative advantage and benefit from different innovations because they produce different goods. In this case, weak IPRs imply that rents from the South are smaller so that the Southern sectors attract less innovation. Thus, by making the sectors in which poor countries are specialized relatively less productive, trade can amplify North–South wage differences. At the same time, the paper shows that trade with weak IPRs countries may reduce the growth rate of the world economy. The reason is that, in the long run, trade equalizes the returns to innovation across sectors and countries through a relative price change. Hence, the disincentive to innovate due to imperfect IPRs enforcement in the South spills over to the North. An interesting aspect of this result is that it applies despite the Northern market for new technologies remaining fully protected by domestic IPRs and independently of the size of the South.

The results of the paper are based on four assumptions: specialization driven by trade, sector-specific (directed) technical progress, imperfect appropriability of profits from innovation in developing countries and gross substitutability between goods. All of them seem plausible. That countries specialize in different sets of products, at least to some extent, appears reasonable.[2] More specifically, the Ricardian model has proven to be useful in the literature on trade and technology and the absence of factor price equalization makes it particularly suitable for analyzing wage differences across countries. Several observations suggest that technical progress has a strong sectoral dimension. For example, R&D is mainly performed by large companies and therefore directed to their range of activities. Although innovation certainly generates spillovers, Jaffe et al. (1993) show that these are generally limited to products in similar technological categories. Infringements of IPRs in developing countries appear to be significant, as proven by the many complaints of companies based in industrial countries. In this respect, the US Chamber of Commerce estimated a profit loss for US firms of about $24 billion in 1988. Finally, a higher than one elasticity of substitution between goods seems realistic, as it yields the sensible prediction that fast growing sectors and countries become relatively richer.

Although the main contribution of the paper is theoretical, it is nonetheless desirable to assess empirically the mechanism it proposes. This is done in the final part of the paper, which is a first attempt at testing two predictions of the model. The first is that protection of IPRs is most beneficial in open countries, because specialization lowers the scope for free-riding on foreign IPRs. To test it, measures of protection for IPRs and other macroeconomic variables have been collected for a panel of 53 countries observed in the years 1965–1990. The main finding is that, consistent with the model, the correlation between IPRs protection and GDP is higher among open countries. The second prediction concerns the mechanism linking North–South trade to the pattern of R&D. According to the model, an increase in import penetration from low-wage, low-IPRs countries should be followed by a fall in R&D investment at the industry level. Data from a panel of US manufacturing sectors observed over the period 1972–1996 provide support for this prediction and show that the impact of North–South trade on the direction of technical change is quantitatively important. On the contrary, import penetration from other industrialized countries does not have such an effect.

This paper is related to various strands of literature. First, it is part of the literature on North–South trade and endogenous growth. A common theme of some of these works (e.g., Young, 1991; Galor and Mountford, 2008) is that trade opening may be less beneficial to LDCs if they specialize in the "wrong" sectors (i.e., those with low growth potential or low human capital intensity). The result of this paper is more general in that it shows how trade can shift innovation in favor of rich countries irrespective of the characteristics of the sectors of specialization. Other works, such as Acemoglu et al. (2006), suggest instead that the effects of trade may depend on characteristics such as the level of technological backwardness of a country or a sector. In comparison, this paper shows that the effect of trade may also depend on the level of protection of IPRs. In particular, the fact that trade opening shifts the direction of innovation in favor of countries where IPRs are better enforced is novel.

[1] The TRIPS agreement establishes minimum standards of protection for several categories of IPRs and a schedule for developing countries to adopt them.
[2] Ohlin went as far as to say that trade means specialization.

The paper is also related to the line of research on "appropriate technologies". Diwan and Rodrik (1991), Acemoglu and Zilibotti (2001) and Saint-Paul (2008) argue that, whenever countries differ in terms of technological needs or preferences, the enforcement of IPRs can be instrumental to stimulate the development of the most appropriate innovations. The contribution of this paper is to show that specialization in production due to trade opening makes the technological needs of countries more diverse and may thus exacerbate the problem of inappropriate technologies.

Finally, the paper is related to the literature on imitation and innovation in a trading world. Some contributions, including Helpman (1993), Glass and Saggi (2002), Dinopoulos and Segerstrom (2004), highlight the potential downsides of strong IPRs protection, as it restricts the efficient allocation of resources across countries. Others, such as Lai (1998), Yang and Maskus (2001), suggest instead that IPRs can foster growth and promote the diffusion of technology. Another group of papers, including Grossman and Lai (2004), Goh and Olivier (2002) and Chin and Grossman (1990), study the incentives that governments have to protect intellectual property in a trading economy. Although all these papers made important contributions, they generally neglect the idea that technologies can be inappropriate for developing countries and that IPRs protection can play a role in attracting better technologies. None of them study how specialization affects the direction of technical progress and thus the type, rather than the quantity, of innovation. The present paper fills this gap.

The rest of the paper is organized as follows. Section 2 presents the basic model, solves for the equilibrium under autarky and free-trade and derives the two main results: that trade integration with countries where IPRs are weakly protected can amplify income differences and can slow down the world growth rate. The model is then extended to study imperfect market integration in the presence of non-traded goods. Section 3 presents supportive empirical evidence. Section 4 concludes.

2. The model

This section describes first the simplest case of a single economy with perfect IPRs protection (the North). The analysis is then extended by adding a second economy (the South) with imperfect IPRs protection. Then, three distinct equilibria are compared: autarky, with and without IPRs protection in the South, and free-trade in goods with imperfect IPRs protection. Finally, non-traded goods are introduced to study a case of partial trade integration.

2.1. Basic setup: the North

Consider first a group of advanced countries, called the North, taken in isolation. The North is assumed to be a collection of perfectly integrated economies with similar characteristics and full protection of IPRs. For now, we take technology as given and we omit any time index. There is a continuum [0, 1] of sectors, indexed by i, producing intermediate goods. Output of each sector, $y\,(i)$, is costlessly aggregated into a final good Y used both for consumption and investment:

$$Y=\left[\int_0^1 y(i)^{\frac{\epsilon-1}{\epsilon}}\mathrm{d}i\right]^{\frac{\epsilon}{\epsilon-1}}, \tag{1}$$

where $\epsilon>1$ is the elasticity of substitution between any two intermediate goods. The relative demand obtained by maximizing Eq. (1) is:

$$\frac{p(i)}{p(j)}=\left[\frac{y(i)}{y(j)}\right]^{-1/\epsilon}. \tag{2}$$

The final good Y is taken as the numeraire and its price index is therefore set equal to one:

$$P=\left[\int_0^1 p(i)^{1-\epsilon}\mathrm{d}i\right]^{\frac{1}{1-\epsilon}}=1. \tag{3}$$

Each intermediate good $y\,(i)$ is homogeneous and produced by competitive firms using a range $N\,(i)$ of machines and labor, $l\,(i)$:

$$y(i)=[\phi(i)l(i)]^{\beta}\int_0^{N(i)} x(i,j)^{1-\beta}\mathrm{d}j,\quad \beta\in(0,1) \tag{4}$$

where $\phi\,(i)$ is an exogenous index of labor productivity and $x\,(i, j)$ is the quantity used of machine $j\in[0,N(i)]$ available in sector i. Machines are sector-specific and depreciate fully after use. Demand for machine $x\,(i, j)$ derived from Eq. (4) is:

$$x(i,j)=\left[\frac{(1-\beta)p(i)}{\chi(i,j)}\right]^{1/\beta}\phi(i)l(i), \tag{5}$$

where $\chi\,(i, j)$ is the price of machine $x(i, j)$.

Each machine in each sector is produced by a monopolist. The unit cost of producing any machine is a free parameter and is set equal to $(1-\beta)^2$ for convenience.[3] Together with isoelastic demand Eq. (2), this implies that all monopolists charge the same price,

[3] This simplification is immaterial because we are not interested in studying the effect of changes in the cost of producing machines.

$\chi(i,j)=\chi=(1-\beta)$. Substituting χ and Eq. (5) into Eq. (4), yields the quantity produced in sector i as a linear function of the level of technology $A(i)\equiv\phi(i)N(i)$ and employed labor $l(i)$:

$$y(i)=p(i)^{(1-\beta)/\beta}A(i)l(i). \tag{6}$$

Given the Cobb–Douglas specification in Eq. (4), the wage bill in each sector is a fraction β of sectoral output. Therefore, Eq. (6) can be used to find a relationship between equilibrium prices and the wage rate:

$$w=\beta p(i)^{1/\beta}A(i). \tag{7}$$

Since there is perfect mobility of labor across sectors, the wage rate has to be equalized in the economy. Dividing Eq. (7) by its counterpart in sector j yields the relative price of any two intermediate goods:

$$\frac{p(i)}{p(j)}=\left[\frac{A(j)}{A(i)}\right]^{\beta}. \tag{8}$$

Intuitively, sectors with higher productivity have lower prices. Solving Eq. (7) for $p(i)$ and substituting this expression into Eq. (3) shows that the equilibrium wage rate is a CES function of sectoral productivity:

$$w=\beta\left[\int_0^1 A(i)^{\sigma}\mathrm{d}i\right]^{1/\sigma}, \tag{9}$$

where $\sigma\equiv\beta(\epsilon-1)$, to simplify notation. Using Eqs. (6) and (8) in Eq. (2) yields the optimal allocation of workers across sectors. Integrating over the interval [0, 1] gives:

$$l(i)=L\frac{A(i)^{\sigma}}{\int_0^1 A(j)^{\sigma}dj}, \tag{10}$$

Note that more productive sectors attract more workers (as long as $\epsilon>1$) because the value of the marginal productivity of labor has to be equalized.[4] Profits from the sale of a single type of machine in sector i are a fraction $\beta(1-\beta)/N(i)$ of the value of sectoral output:

$$\pi(i)=\beta(1-\beta)p(i)^{1/\beta}\phi(i)l(i). \tag{11}$$

2.1.1. Equilibrium technology

We now discuss the characteristics of technology and study its endogenous evolution. As already stated, overall productivity in each sector, $A(i)$, is the product of two components: an exogenously given productivity parameter, $\phi(i)$, and the level of technical knowledge in sector i, represented by the number of machines $N(i)$. While $\phi(i)$ is fixed and determined by purely exogenous factors, such as geography, $N(i)$ can be increased through innovation as in models of endogenous growth with expanding variety of products. Following Romer (1990), the level of technical knowledge in a sector is represented by the number of available machines, that can be interpreted as the extent of specialization.[5] More specifically, innovation is costly, directed and sector-specific: i.e., the innovator can choose in which sector to innovate and a new machine in sector i cannot be used in any other sector j. To design a new variety of machines, the innovator has to pay a cost of μ units of the numeraire Y. Once a new machine is discovered, the innovator is granted a patent that entails a perpetual monopoly over its use. The patent is then sold to a firm that becomes the sole producer of that type of machine. Free-entry in the R&D sector implies that the present discounted value of profits from innovation cannot exceed the entry cost μ. Along a balanced growth path with positive innovation, $\pi(i)$ and r are constant (this will be proved later) so that the free-entry condition can be written as:

$$\frac{\pi(i)}{r}=\mu. \tag{12}$$

Using Eqs. (11), (10), (9), (7) and setting $\mu=(1-\beta)\beta$, the above expression reduces to[6]:

$$L\phi(i)\left[\frac{w}{\beta A(i)}\right]^{1-\sigma}=r. \tag{13}$$

For the remainder of the paper, we assume $\sigma\in(0,1)$. On the one hand, the assumption $\sigma>0$ (equivalent to $\epsilon>1$) rules out immiserizing growth, whereby a sector (later on a country) growing faster than the others would become poorer in relative terms. On the other hand, the restriction $\sigma<1$ is required to have a stable income distribution across sectors: it implies that if a sector grows more than another, its profitability falls due to the adverse movement of its relative price, discouraging further innovation. If this condition were violated, it would be profitable to innovate in one sector only and all the others would disappear

[4] Eq. (10) provides an economic interpretation for σ: it is the elasticity of sectoral employment to sectoral productivity.

[5] See Gancia and Zilibotti (2005) for a survey of this class of models.

[6] Setting $\mu=(1-\beta)\beta$ is meant to simplify the algebra only. It is innocuous, since the paper does not study the effects of changes in the cost of innovation μ.

asymptotically. This case does not seem very realistic and is thus ruled out.[7] From this discussion, it should be clear that along a balanced growth path R&D must be performed in all sectors so that they all grow at the same rate. For this to be the case, the incentive to innovate has to be equalized across sectors. Imposing condition Eq. (13) for all i, it is possible to characterize the long-run relative productivity across sectors:

$$\frac{A(i)}{A(j)} = \left[\frac{\phi(i)}{\phi(j)}\right]^{\frac{1}{1-\sigma}}. \tag{14}$$

Eq. (14) shows that, as long as $\sigma>0$ (i.e., $\epsilon>1$), innovation amplifies the exogenously given productivity differences $\phi(i)/\phi(j)$: in order to equalize the returns to innovation, exogenously more productive sectors need to have a higher than average $N(i)$.

For later reference, it is useful to express instantaneous profits as a function of exogenous parameters only. To this end, integrate Eq. (14) across sectors and substitute it, together with Eqs. (10), (9) and (7), into Eq. (11) to get:

$$\pi = \beta(1-\beta)L\left[\int \phi(i)^{\frac{\sigma}{1-\sigma}}\mathrm{d}i\right]^{\frac{1-\sigma}{\sigma}}. \tag{15}$$

Thus, instantaneous profits are a CES function of exogenous productivities $\phi(i)$ and proportional to population L.

2.1.2. Households and the balanced growth rate

We now consider the dynamic maximization problem of households and introduce the time index when necessary. Consumers maximize identical isoelastic preferences:

$$U\int_0^{\infty} \ln c(t) e^{-\rho t}\mathrm{d}t,$$

where $c(t)$ is consumption and $\rho>0$ the discount factor. The representative household is subject to the dynamic budget constraint $\dot{a}(t)=w(t)+r(t)a(t)-c(t)$, where $a(t)$ represents assets. Standard techniques yield the familiar Euler equation:

$$g(t) = \frac{\dot{c}(t)}{c(t)} = r(t)-\rho. \tag{16}$$

Using Eqs. (12), (15) and (16) the balanced growth rate of the economy can be found as:

$$g(t) = g = L\left[\int_0^1 \phi(i)^{\sigma/(1-\sigma)}\mathrm{d}i\right]^{(1-\sigma)/\sigma} - \rho. \tag{17}$$

Note that the growth rate depends on the size of the economy.[8] Yet, it is important to stress that the main results of this paper do not hinge on this scale effect (the Appendix A shows how it can be removed while preserving most of the analysis). Finally, we can verify that c, Y and N all grow at the common rate g. To see this, write the resource constraint of the economy:

$$c + I_X + I_{\mathrm{R\&D}} \le Y = \frac{wL}{\beta} = \left[\int_0^1 A(i)^{\sigma}\mathrm{d}i\right]^{1/\sigma} L, \tag{18}$$

where $I_X=(1-\beta)^2\int_0^1 N(i)x(i)di$ is the cost of producing machines and $I_{\mathrm{R\&D}}=\mu\int_0^1 \dot{N}(i)di$ is the cost of innovation. Note that Y, I_X and $I_{\mathrm{R\&D}}$ grow at the same rate as $N(i)$.[9] To satisfy Eq. (18), consumption must grow at the same rate too.

2.2. Imitation and the South

Consider now a set S of less developed countries, called the South. From now on, the subscripts N and S will be used whenever necessary to distinguish the North and the South, respectively. The South is assumed to have a schedule of exogenous labor productivity, $\phi_S=(\phi_S(i))$, different from that of the North, $\phi_N=(\phi_N(i))$. These Ricardian differences capture the fact that geographic, institutional and economic differences (taken as given) make the South relatively more productive in some sectors than the North, even when technical knowledge is common. Following Dornbusch et al. (1977), sectors are conveniently ordered in such a way that the index $i\in[0, 1]$ is decreasing in the comparative advantage of the North, i.e., $\phi_N(i)/\phi_S(i)>\phi_N(j)/\phi_S(j)$ if and only if $i<j$.

The way imitation is modeled follows Acemoglu (2003) and Acemoglu and Zilibotti (2001) and emphasizes the quasi-public good nature of knowledge, according to which ideas can flow rapidly across borders. In particular, we make the following assumptions. First, the North innovates while the South can only imitate.[10] Second, technically, blueprints of all inventions can be

[7] When trade is allowed, this assumption yields a stable distribution of income across countries. Evidence on this is provided by Acemoglu and Ventura (2002). In particular, they estimate $\epsilon=2.3$ which, together with a labor share $\beta=0.66$, implies $\sigma=0.85$. Similar values for 03F5 are estimated by Epifani and Gancia (in press). Thus, the restriction $\sigma\in(0, 1)$ seems empirically plausible.

[8] More precisely, the growth rate depends on the ratio between the size of the economy and the cost of innovation, although the latter does not appear in Eq. (17) because of our normalization. Provided that the cost of innovation does not depend on L, changes in population will affect the growth rate precisely as implied by Eq. (17).

[9] Recall that $A(i)=N(i)\phi(i)$ and that $x(i)$ is constant along the balanced growth path.

[10] This is a reasonable case. However, given that innovation is for the global market, the location of the R&D sector is immaterial for the results.

obtained costlessly, but legally imitators must pay a fixed royalty fee to the innovator.[11] More precisely, the first imitator is granted by the Southern government monopoly power in producing the copied machine, but is also required to pay to the original innovator a fraction $\theta \in [0,1]$ of the value of the blueprint in the South. When IPRs are fully protected, $\theta=1$, the royalty fee is exactly equal to the present discounted value of the stream of monopoly profits earned from selling the machine in the South. When $\theta=0$, on the contrary, innovators do not receive any payment from the Southern market. In any case, however, the endogenous component of technology, $N(i)$, is identical in all countries and all machines are sold by local monopolists.[12] Thus, the role of θ is just to determine how much of the revenue from selling machines in the South accrues to the original innovator and can be interpreted as an index of the strength of IPRs protection.[13] Third, machines are non-traded, even when trade in goods is possible. This assumption implies that, consistent with most patent laws, firms in the South are never allowed to re-export copied machines to the Northern market and is meant to simplify the analysis by ruling out competition between producers of machines in the North and in the South.[14] Forth, throughout, we maintain the assumption that final good markets remain fully competitive in all countries.

Note that, despite the fact that the North and the South have access to the same innovations, their productivity will generally differ for two reasons: first, because of the exogenous differences in labor productivity ϕ_N and ϕ_S, and second, as it will be shown soon, because innovations may be more appropriate for a country than the other.

2.3. Case I: no trade and $\theta=0$

Consider first the simplest case in which there is no IPRs protection in the South (i.e., $\theta=0$) and no trade in goods. In this case, the equilibrium in the North is the one described in Section 2.1 and is unaffected by the presence of the South. In particular, the state of technology across sectors, $N(i)$, is given by Eq. (14) according to the exogenous labor productivity of the North, $\phi_N(i)$. The equilibrium in the South is characterized by a set of equations analogous to those that apply to the North, with the difference that machines are copied and thus $N(i)$ is taken as given from the North. Then, using Eqs. (9) and (14) it is possible to solve for the North–South wage gap, expressed in units of the common numeraire Y:

$$\omega \equiv \frac{w_N}{w_S} = \left[\frac{\int_0^1 \phi_N(i)^{\sigma/(1-\sigma)} \mathrm{d}i}{\int_0^1 \phi_N(i)^{\sigma^2/(1-\sigma)} \phi_S(i)^{\sigma} \mathrm{d}i}\right]^{1/\sigma}. \tag{19}$$

First, note that $\partial\omega/\partial\phi_N(i)>0$ and $\partial\omega/\partial\phi_S(i)<0$. Intuitively, the relative wage is proportional to the exogenous productivity of the two regions, ϕ_N and ϕ_S. More important, the Appendix A shows that the sectoral profile of technology is appropriate for the North, in the sense that it maximizes Y_N, while it is appropriate for the South only in the limit case in which ϕ_N and ϕ_S are proportional to each other so that there is no comparative advantage (i.e., $\phi_S(i)=\alpha\phi_N(i)$, $\forall i$, with $\alpha>0$ equal to a constant of proportionality).[15] This result extends the finding of Acemoglu and Zilibotti (2001) that technologies developed in advanced countries may be inappropriate for the economic conditions of LDCs.[16] The Appendix A also shows that, $\forall\sigma\in(0,1)$, ω is bounded by max $\{\phi_N(i)/\phi_S(i)\}=\phi_N(0)/\phi_S(0)$. Lastly, since growth is due to the expansion of $N(i)$ that are identical across countries, Eq. (17) for the North gives also the growth rate of the South.

2.4. Case II: no trade and $\theta\geq 0$

Consider now the more general case of imperfect protection of IPRs in the South: $\theta\in[0,1]$. In this case, profitability of an innovation is given by the sum of the rents from both the markets in the North and in the South. Then, the free-entry condition whereby the value of innovation must be equal to its cost becomes:

$$\frac{[\pi_N(i)+\theta\pi_S(i)]}{r}=\mu.$$

[11] The royalty fee is in terms of the aggregate Y. As in models of international finance, we assume that payments of Y may be allowed even when there is no trade in $y(i)$. Alternatively, the royalty fee could be spent locally, for example, in training and supervising costs.

[12] When the fixed royalty fee is strictly positive, allowing for competition between imitators does not affect the equilibrium market structure. If the same machine is copied by more then one firms, Bertrand competition would lower its price to the marginal cost. In this case, no firms will be able to recover the fixed cost of the royalty fee. Anticipating negative profits, a second imitator will not enter.

[13] The obvious limit of this approach to IPRs is that the monopoly distortion in the South does not depend on θ. This simplification is innocuous except for welfare analysis, which is not in the scope of the paper. Alternatively, one could assume that imitated products are sold at marginal cost and model IPRs protection as an additional per-unit cost that must be paid to the original innovator in the form of royalties. For example, the unit cost inclusive of royalties could be defined as $(1-\beta)(1+\beta\theta-\beta)$, so that $\chi_S=\chi_N=(1-\beta)$ if $\theta=1$ and $\chi_S=(1-\beta)^2<\chi_N$ if $\theta=0$. The qualitative results of the paper would carry over.

[14] Of course, in reality advanced countries do export technology and equipment to the rest of the world. See, for example, Caselli and Wilson (2004) and Eaton and Kortum (2001). Yet, this evidence is not inconsistent with the model if the royalty fee from selling machines in the South is interpreted as a form of trade in technology and equipment. On the contrary, the fact that most of the world physical capital is produced by a small number of R&D intensive countries is consistent with the view of this paper that technology originates from the North only.

[15] In fact, it is optimal to have a relatively high level of technology $N(i)$ in sectors where the exogenous labor productivity $\phi(i)$ is already high. Copying the technology from the North, the South is using too many machines in sectors that are originally not very productive. This inefficiency lowers the wage in the South.

[16] In their model, this happens because of a skill–technology mismatch: the Northern technology is too skill-biased for the skill-endowment of the South. Here, any source of comparative advantage captured by ϕ_N and ϕ_S implies that the North and the South have different technological needs.

Note that an innovator can extract only a fraction θ of the profits from the Southern market. Substituting the expressions for profits using Eqs. (11), (10), (9), (7) and solving for $N(i)$ yields:

$$N(i)=\frac{1}{\beta}\left[\frac{L_N\phi_N(i)^{\sigma}(w_N)^{1-\sigma}+\theta L_S\phi_S(i)^{\sigma}(w_S)^{1-\sigma}}{r}\right]^{1/(1-\sigma)}. \qquad (20)$$

The endogenous component of productivity, $N(i)$, is now proportional to a weighted average of the two exogenous indexes $\phi_N(i)$ and $\phi_S(i)$, with weights that depend on country size, the strength of property rights and relative income. Case I is recovered from Eq. (20) setting $\theta=0$. Using Eqs. (9), (20) and recalling the definition $A(i)\equiv\phi(i)N(i)$, the implicit formula for the relative wage is:

$$\omega=\left\{\frac{\int_0^1\phi_N(i)^{\sigma}\left[L_N\phi_N(i)^{\sigma}+\theta L_S\phi_S(i)^{\sigma}(\omega)^{\sigma-1}\right]^{\sigma/(1-\sigma)}\mathrm{d}i}{\int_0^1\phi_S(i)^{\sigma}\left[L_N\phi_N(i)^{\sigma}+\theta L_S\phi_S(i)^{\sigma}(\omega)^{\sigma-1}\right]^{\sigma/(1-\sigma)}\mathrm{d}i}\right\}^{1/\sigma}. \qquad (21)$$

Whether technology is closer to the Northern or Southern optimum, depends on which of the two markets for innovations is larger (see the Appendix A for further details). As $\theta L_S/L_N\to 0$, Eq. (21) approaches Eq. (19) from below. Therefore, the case of no IPRs protection defines an upper bound for ω in autarky.

Finally, using Eqs. (20), (9) and the Euler equation $g=r-\rho$, the growth rate of the world economy for the general case when $\theta\in[0,1]$ can be found as:

$$g=\left\{\int_0^1\left[L_N\phi_N(i)+\theta L_S\phi_S(i)^{\sigma}(\phi_N(i)/\omega)^{1-\sigma}\right]^{\sigma/(1-\sigma)}\mathrm{d}i\right\}^{(1-\sigma)/\sigma}-\rho. \qquad (22)$$

Note that the world growth rate is increasing in θ because stronger IPRs protection translate into higher rewards to innovation. As $\theta\to 0$, the growth rate declines to Eq. (17), defining a lower bound for the growth rate in autarky.

2.5. Case III: free-trade with $\theta\geq 0$

Consider now the possibility to trade $y(i)$ internationally. The exchange of goods between the North and the South is profitable because of Ricardian comparative advantage. Even if technical progress is endogenous and identical everywhere, sectoral productivity differences across countries are fixed by ϕ_N and ϕ_S, and so is the pattern of comparative advantage.[17] Recall that the ordering of sectors $i\in[0,1]$ is decreasing in the comparative advantage of the North, so that $\phi_N(i)/\phi_S(i)>\phi_N(j)/\phi_S(j)$ if and only if $i<j$. This means that the North is better at producing goods with a low-index i. Further, for analytical tractability, the comparative advantage schedule, $\phi_N(i)/\phi_S(i)$, is assumed to be continuous. As in Dornbusch et al. (1977), the equilibrium under free-trade and for a given technology can be found imposing two conditions. The first is that each good is produced only in the country where it has a lower production price. This implies that the North specializes in the sectors $[0, z)$ where its comparative advantage is stronger and the South produces the remaining range of goods $(z, 1]$. Given the continuity of $\phi_N(i)/\phi_S(i)$, the North and the South must be equally good at producing the cut-off commodity z: $p_N(z)=p_S(z)$.[18] Using Eq. (7), this condition identifies the cut-off sector z as a function of the relative wage under free-trade ω:

$$\frac{\phi_N(z)}{\phi_S(z)}=\omega. \qquad (23)$$

For a given relative wage, Eq. (23) gives the pattern of specialization between the two countries. Since comparative advantage of the North is decreasing in z, Eq. (23) traces a downward sloping curve, Φ, in the space (z,ω). The second equilibrium condition is trade balance, i.e., imports and exports have to be equal in value. Since total output in a country is proportional to the wage bill and the demand share for a set $[0, z]$ of goods is $\int_0^z p(i)^{1-\epsilon}di$, trade balance can be written as:

$$w_NL_N\int_z^1 p(i)^{1-\epsilon}\mathrm{d}i=w_SL_S\int_0^z p(i)^{1-\epsilon}\mathrm{d}i,$$

where the left hand side is the value of imports in the North and the right-hand side is the value of imports in the South. Note that, by homogeneity of tastes, the location of the final demand for Y (including R&D spending and profits) is irrelevant.[19] Using Eq. (7), the trade balance condition can be rewritten as:

$$w_N^{1+\sigma}L_N\int_z^1 A(i)^{\sigma}\mathrm{d}i=w_S^{1+\sigma}L_S\int_0^z A(i)^{\sigma}\mathrm{d}i. \qquad (24)$$

[17] This is of course a simplification. Saint-Paul (2008) makes the same assumption, while Taylor (1994) builds a model where comparative advantage is endogenous and may depend on IPRs policies.

[18] Since goods $y(i)$ are produced by competitive firms, no one can undercut the price in face of foreign competition. Further, given that each monopolist is infinitesimal, it has no incentive to undercut the price of its machine to make an industry more competitive.

[19] Trade balance is here equivalent to market clearing:

$$Y_N=(Y_N+Y_S)\int_0^z p(i)^{1-\epsilon}\mathrm{d}i,$$

where the left hand side is supply from the North and the right-hand side is demand for goods from the North. Royalty fees only affect the split (Y_N+Y_S) on the right-hand side, but leave the overall condition unaffected.

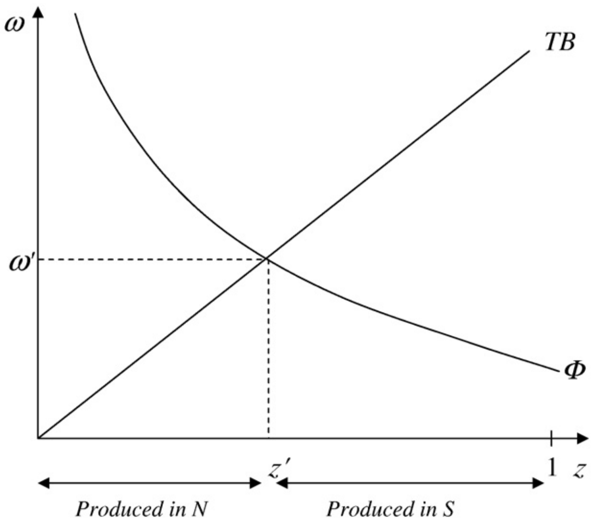

Fig. 1. Free-trade equilibrium.

Along a balanced growth path, profits from innovation in any pair of sectors must be equal. In particular, considering innovations for goods i and j produced in the North and in the South respectively, the following research-arbitrage condition must hold: $\pi_N(i)=\theta\pi_S(j)$. Substituting Eq. (11) for profits, noting that under free-trade the optimal allocation of labor Eq. (10) is $l_N(i)=L_N A_N(i)^\sigma / \int_0^z A_N(v)^\sigma dv$ and $l_S(j)=L_S A_S(j)^\sigma / \int_z^1 A_S(v)^\sigma dv$ and using Eq. (24), yields the relative productivity compatible with balanced growth:

$$\frac{A_N(i)}{A_S(j)}=\left[\frac{\phi_N(i)}{\theta\phi_S(j)}\right]^{1/(1-\sigma)}(\omega)^{\sigma/(\sigma-1)}, \tag{25}$$

$\forall i, j \in [0, 1]$ with $i<z<j$. Compared to the case without trade, the relative productivity of sectors still depends on the exogenous component $\phi(i)$, but also on the IPRs regime of the country where the innovation is used. Technology is still biased towards more productive sectors (as $\sigma\in(0, 1)$, original differences $\phi_N(i)/\phi_S(j)$ are amplified) but also against the Southern sectors where rents from innovation are lost (as long as $\theta<1$). Hence, Eq. (25) shows that under free-trade weak protection of IPRs in the South shifts technology in favor of the goods produced by the North.

Integrating i over $[0, z]$ and j over $[z, 1]$ in Eq. (25) and using Eq. (24), the trade balance condition (TB), incorporating the research-arbitrage condition that must hold along the balanced growth path, can be rewritten as:

$$\omega=\left(\frac{1}{\theta}\right)^{\sigma}\left[\frac{L_S\int_0^z\phi_N(i)^{\sigma/(1-\sigma)}\mathrm{d}i}{L_N\int_z^1\phi_S(i)^{\sigma/(1-\sigma)}\mathrm{d}i}\right]^{1-\sigma}. \tag{26}$$

Note that ω is increasing in z and decreasing in θ. Further, if $\sigma=0$ (or $\epsilon=1$, as in the Cobb–Douglas case), the equilibrium is independent of the sectoral distribution of productivity and the degree of IPRs protection. Conversely, as $\sigma\rightarrow 1$ the relative wage becomes determined exclusively by IPRs protection.

The long-run free-trade equilibrium can now be found in Fig. 1 as the intersection of the two schedules Φ Eq. (23) and TB Eq. (26). The graph can be used to study the effects of weak IPRs in the South when international trade is allowed. From Eq. (26), a fall in θ implies an upward shift of the TB schedules which lower the relative wage in the South and increases the set of goods produced there (z falls). Comparing Eq. (26) with Eq. (19), and noting that $\lim_{\theta\rightarrow 0}\omega=\max \phi_N(i)/\phi_S(i)$, proves the following:

Proposition 1. *Suppose that parameters (L_N, L_S, ϕ_N, ϕ_S, σ and ρ) are such to guarantee positive long-run growth and $\sigma\in(0, 1)$. Then, there exists a level θ^* such that if $\theta<\theta^*$ the North South wage gap, ω, is larger when trade in $y(i)$ is allowed.*

This is one of the main results of the paper: trade can amplify wage and productivity differences if protection of IPRs in less developed countries is too low. Proposition 1 is based on the interplay between specialization and weak IPRs in developing countries. First, trade and specialization imply that the North and South use different sets of innovations. Second, weak IPRs make innovations directed to the South less profitable. Hence, trade may shift technology in favor of rich nations. As $\theta\rightarrow 0$, R&D is directed towards Northern sectors only and the wage gap grows up to its maximum ($\phi_N(0)=\phi_S(0)$), irrespective of any other country characteristics.[20] In autarky, instead, even with $\theta=0$, the South still benefits from the innovations performed in all sectors for the Northern market.

[20] Acemoglu and Zilibotti (2001) show instead that trade leads to skill-biased technical change. However, in their model trade generates productivity convergence and has ambiguous effects on relative income, even when $\theta=0$ (the only case they study). The main reason for these different results is that they use a Heckscher–Ohlin trade model with factor price equalization.

Another interesting result can be found by calculating the long-run growth rate of the world economy in free-trade (see the Appendix A for the derivation):

$$g^{\mathrm{FT}} = L_N \left[\int_0^z \phi_N(i)^{\frac{\sigma}{(1-\sigma)}} \mathrm{d}i \right]^{\frac{1-\sigma}{\sigma}} \left(1 + \frac{L_S}{L_N} \frac{1}{\omega} \right)^{1/\sigma} - \rho. \tag{27}$$

Note that the growth rate of the world economy is increasing in θ: a higher θ expands the range z of goods produced in the North and decreases ω, all effects that contribute to raising the growth rate in Eq. (27). The intuition is simple and is the common argument in favor of IPRs protection: better enforcement of IPRs strengthens the incentives to innovate and therefore fosters growth. What is more surprising is that the growth rate of the world economy approaches zero if θ is low enough. This is in contrast to the case without international trade, where the growth rate is bounded from below by the growth rate of the North economy taken in isolation Eq. (17).

The reason behind this result is that weak IPRs in the South spills over to Northern sectors because trade equalizes the long-run returns to innovation across sectors and countries (i.e., $\pi_N(i)=\theta\pi_S(j)$). In turn, this is possible because returns to innovation in a given sector fall asymptotically to zero as the sector grows faster then the rest of the economy, a consequence of $\sigma\in(0,1)$. Thus, balanced growth is achieved by expanding the Northern sectors up to the point where further investment in innovation for Northern sectors is no more profitable than it is for Southern sectors. This happens through a price effect induced by specialization: as the North specializes in a smaller range of sectors, the increase in production per sector translates into lower relative prices and thus reduced profitability. Note that this result is independent of the size of the South and holds despite the Northern market for new technologies remaining fully protected by domestic IPRs.[21]

Comparing the growth rate in free-trade, Eq. (27), and autarky, Eq. (17), and noting that Eq. (27) is a continuous function of θ with $\lim_{\theta\to\theta>0} g^{FT}=0$, proves the following:

Proposition 2. *For any $\sigma\in(0,1)$, there exists a level θ^{**} such that, if $\theta<\theta^{**}$, the long-run world growth rate is lower when international trade is allowed.*

In summary, Propositions 1 and 2 imply that if protection of intellectual property is too low in less developed countries, trade integration can either amplify North–South wage differences, slow down the world growth rate, or both.[22]

2.6. Non-traded goods

The introduction of non-traded goods gives rise to a regime the combines the free-trade and the autarky equilibrium. Following Dornbusch et al. (1977), assume that a fraction t of income is everywhere spent on internationally traded goods and a fraction $(1-t)$ on non-traded goods.[23] In particular, define consumption over two final of goods:

$$C=(Y)^t(Y^*)^{1-t},$$

where Y, representing the traded component of consumption, is still given by Eq. (1), while Y^* is an aggregate of non-traded goods. In this section, all variables related to the non-traded sectors are denoted by an asterisk. To preserve symmetry, output of the non-traded good, Y^*, is defined by a CES function over a new [0, 1] interval of (non-traded) intermediate products as in Eq. (1). In fact, it is convenient to model the two sectors, traded and non-traded, as similar in all respects and independent from each other, in that each sector uses its own output as the only input to produce its machines and innovation. As before, the price index of the traded good Y is set equal to one, while the price of Y^* is P^*. Under these assumptions and for given wages and technology, the equilibrium conditions in the traded sector are almost unchanged. The only difference is that, due to Cobb–Douglas preferences and symmetry in market structure, only a fraction t of the total labor force is allocated in each country to the traded sector. Likewise, equilibrium conditions in the non-traded sector in any country can be derived as:

$$x^*(i) = [p^*(i)/P^*]^{1/\beta}\phi^*(i)l^*(i) \tag{28}$$

$$y^*(i) = [p^*(i)/P^*]^{(1-\beta)/\beta}A^*(i)l^*(i) \tag{29}$$

$$w = \beta p^*(i)^{1/\beta}P^{*(\beta-1)/\beta}A^*(i) \tag{30}$$

$$w = P^*\beta\left[\int_0^1 A^*(i)^\sigma \mathrm{d}i\right]^{1/\sigma} \tag{31}$$

$$\pi^*(i) = \beta(1-\beta)p^*(i)^{1/\beta}P^{*(\beta-1)/\beta}\phi^*(i)l^*(i), \tag{32}$$

where $P^*=\left[\int_0^1 p^*(i)^{1-\epsilon}di\right]^{\frac{1}{1-\epsilon}}$. These conditions are analogous to Eqs. (5)–(7), (9) and (11), with the difference that the price of the non-traded basket is not normalized to one. Hence, machines in the non-traded sector are sold at the monopoly price $(1-\beta)P^*$ (instead

[21] Note also that sector-specific technical process is crucial. In a setup with factor-specific innovations, as in Acemoglu and Zilibotti (2001), the market size for any innovation depends on exogenous endowments that are unaffected by specialization and trade: for this reason, incentives to invest in R&D would never go to zero even if $\theta=0$. As a consequence, in Acemoglu and Zilibotti (2001) trade opening has no effect on the world growth rate.

[22] These results are derived in a model where growth is a positive function of market size. As already stated, this scale effect is not crucial for the main results. Given that the scale effect is often considered implausible, the Appendix A shows how to remove it.

[23] Non-traded goods can also arise endogenously in the presence of a trade cost. See Dornbusch et al. (1977) for more details.

of $1-\beta$). Finally, assuming that the cost of developing new machines for the non-traded sector is μ units of Y^*, the relative productivity among non-traded goods can be found imposing the arbitrage condition: $\pi(i)=\pi(j)\ \forall\ i, j\in[0, 1]$.

For a given wage, the price of traded goods does not depend on the non-traded sector. Thus, the condition for efficient specialization is still given by Eq. (23). Trade balance is also unaffected, because every country spends the same share t of total income on the traded goods. Thus, Eq. (26) still applies. However, the price of non-traded goods will generally differ across countries. To take this into account, it is possible to rewrite the equilibrium conditions Eqs. (23) and (26) in terms of the real wages: $\omega^R=\omega\,(P_S^*=P_N^*)^{1-t}$. Using Eq. (31) to substitute for the price of non-traded goods yields:

$$\omega^R = \left[\frac{\phi_N(z)}{\phi_S(z)}\right]^t \left(\frac{A_N^*}{A_S^*}\right)^{1-t}$$

$$\omega^R = \theta^{-t\sigma}\left[\frac{L_S\int_0^z \phi_N(i)^{\sigma/(1-\sigma)}\mathrm{d}i}{L_N\int_z^1 \phi_S(i)^{\sigma/(1-\sigma)}\mathrm{d}i}\right]^{t(1-\sigma)}\left(\frac{A_N^*}{A_S^*}\right)^{1-t},$$

where $A_j^*\equiv\left[\int_0^1 A_j^*(i)^\sigma di\right]^{1/\sigma}, j=N, S$, is an aggregate measure of productivity in the non-traded sector, that will depend, among other things, on $\phi_N^*(i)$, $\phi_S^*(i)$ and θ. Note that, as $t\to 1$ the economy approaches the free-trade equilibrium. Conversely, as $t\to 1$ the wage ratio converges to the relative productivity of labor in the non-traded sector of the two countries, A_N^*/A_S^*, which reduces to Eq. (21), just as in the autarky case. Similarly, it is possible to show that the growth rate is given by a combination of the formulas valid in autarky and in free-trade.

At this point, it is instructive to isolate the mechanism emphasized in the paper by considering a simple case in which the two countries are perfectly symmetric except for the degree of protection of IPRs, θ. In particular, assume that the two countries have the same size, $L_N=L_S$, the same productivity in the non-traded sectors, $\phi_N^*(i)=\phi_S^*(i)$ implying $A_N^*=A_S^*$, and the same *average* productivity in the traded sectors. However, the North and the South still differ in how the exogenous component of labor productivity is distributed across the traded sectors. For example, assume that $\phi_N(i)=\phi_S(1-i)$. In such a situation, no country is inherently better than the other.[24] Then, it easy to show that the relative wage in autarky is one and that the following inequalities hold:

$$\frac{\partial\omega^R}{\partial t}\geq 0,\quad \frac{\partial\omega^R}{\partial\theta}\leq 0,\quad \frac{\partial^2\omega^R}{\partial\theta\partial t}<0,$$

i.e., the North–South wage ratio increases with the extent of trade (t) whenever IPRs are not fully protected in the South. Further, the North–South wage ratio falls with IPRs protection in the South (θ), the more so the higher the extent of trade (t). Moving back to the general case, it is straightforward to use Proposition 1 to show that, if θ is low enough, real wage differences will increase with the extent of trade (t).

2.7. Why are IPRs not protected in the South?

The previous analysis suggests that Southern countries may benefit from the enforcement of IPRs. It is then interesting to ask why these policies are often not adopted. Although this question goes beyond the scope of the paper, a number of possible answers come to mind. First of all, enforcing IPRs can be costly, particularly in countries with weak legal institutions. A second reason might be that a tightening of IPRs implies a profit loss. Therefore, it may be optimal from the point of view of the South not to have full protection of IPRs. Even when strong protection of IPRs is in the interest of the South, the government might fail to implement the optimal policy for political reasons: if the group of monopolists that enjoy the rents from imitation has more political power than the workers, it may prefer to defend profits at the expenses of the rest of the economy.

In implementing IPRs protection, there might also be a coordination problem among Southern governments: each of them prefers the others to enforce IPRs, in order to attract innovation, but has an incentive to free ride not enforcing these property rights itself. However, this depends on the pattern of specialization and on the size of each country. If each Southern country specialized in a different set of commodities, then the coordination problem would disappear. Similarly, a large country would have a higher incentive to protect IPRs because of its larger impact on world innovation and its limited ability to benefit from others' policies.

Finally, the literature on IPRs policies and welfare shows that perfect protection is generally not optimal when patents also affect monopoly distortions. Moreover, the optimal IPR strength is typically found to be weaker in the South (see, for example, the important article by Grossman and Lai, 2004). Studying optimal policy in the present model would require accounting explicitly for profit transfers and changing our simplifying assumption that the IPR policy does not affect monopoly pricing in the South. Such an analysis goes beyond the scope of this paper.

[24] The assumption that there is a pattern of comparative advantage in traded sectors (i.e., $\phi_N(i)\neq\phi_S(i)$) while there is none in non-traded sectors (i.e., $\phi_N^*(i)=\phi_S^*(i)$) is a simplification that captures, albeit in an extreme fashion, what would be a general result if non-traded goods arose endogenously due to the presence of a trade cost: that comparative advantage would be stronger among traded goods. The reason is that non traded goods would be precisely those for which comparative advantage (i.e., the price difference between the two countries) is not strong enough to justify spending the trade cost.

3. Empirical evidence

The aim of this section is to provide a first attempt at assessing the empirical plausibility of the mechanism proposed in this paper. This is done in three parts. The first is a test of the model's prediction whereby IPRs protection is most beneficial in open countries, using cross-country macro data. The second part is an attempt to test whether North–South trade has affected the pattern of R&D, using US industry-level data. The third part, instead, compares the model to the existing literature and discusses the available evidence in favor of the different approaches.

3.1. Trade, IPRs and productivity

In our model, trade-driven specialization affects the ability of a country to attract better technologies by changing the level of protection of IPRs. While a country in autarky can free ride on innovations from the rest of the world, trade-induced specialization implies that countries use different innovations so that the scope for free-riding is more limited. By increasing a country's share of world production (and profits) in the sectors of comparative advantage, specialization increases the impact of domestic policies on profitability of innovations directed to those sectors, thereby increasing the ability of a country to attract technologies tailored to its needs. For this reason, the model suggests the positive effect of increasing IPRs protection of a country, θ_i, on its productivity and income to be higher under free-trade than in autarky or, more generally, the larger the extent of trade. Further, since the ability of a country to attract innovation for its own sectors depends on its share in world production of those sectors, which in turn depends on country size, the model suggests the impact of θ_i on productivity to be higher in larger countries.[25] These implications can be summarized as:

$$\frac{\partial^2 (Y_i/\overline{Y})}{\partial\theta_i\partial t_i} > 0 \quad \text{and} \quad \frac{\partial^2 (Y_i/\overline{Y})}{\partial\theta_i\partial L_i} > 0, \tag{33}$$

where Y_i is the real GDP per worker in country i, $\overline{Y}$ is the world average, L_i is the size of country i and t_i the size of its traded sector.

To test Eq. (33), measures of GDP per worker, IPRs protection, openness to trade and country size have been collected for a panel of countries from 1965 to 1995. GDP per worker (GPDW) is taken from the Penn World Table 6.0 (PWT6.0). Two important determinants of productivity are also included in the analysis, to capture some of the cross-country differences in the ϕ: the stock of physical capital per worker (KL), from PWT6.0, and the fraction of working age population with at least secondary schooling as a proxy for human capital (HL), from Barro and Lee (2001). As for trade openness, two different measures are considered: the Sachs and Warner (1995) index, which is a dummy taking value one if a country is classified as open, and the trade share in total GDP from PWT6.0.[26] Although the first measure is useful to distinguish countries under different trade regimes, it exhibits almost no time variation in the given sample and is therefore more appropriate for cross-sectional analysis. The second measure instead, captures well the increase in market integration over time. Country size is measured by total population (POP), as reported in PWT6.0.[27] The last challenge is to find data on the degree of protection of intellectual property. In this respect, this study uses the index of patent rights built by Ginarte and Park (1997). Although patents are only a component of IPRs, they are likely to be correlated with the overall level of protection for intellectual property. This index has the advantage of being available for a large number of countries with quinquennial observation since 1965. The index (IPR) ranges from 0 to 5.[28] In summary, the overall dataset comprises a cross-section of 53 countries and 6 time observations, from 1965 to 1990 at 5-year intervals.[29] Descriptive statistics of the main variables are reported in Table 1.

To get a first sense for the patterns in the data, Table 2 presents a set of conditional correlations. The results are encouraging. As expected, IPRs protection is associated with higher productivity for countries classified as open by Sachs and Warner, while the correlation is zero for closed economies. Likewise, being open has a much higher correlation with productivity in countries with strong patent rights. Also the second prediction in Eq. (33) seems broadly consistent with the data, as IPRs protection is found to have a higher correlation with productivity in larger countries.

To better display these correlation, we first estimate with pooled OLS the following equation:

$$\text{GDPW}_{it} = b_0 + b_1(\text{IPR}_{it-5}) + b_2(\text{OPEN}_{it-5}) + b_3(\text{OPEN}_{it-5}{*}\text{IPR}_{it-5}) + b_4(\text{POP}_{it-5}) + b_5(\text{POP}_{it-5}{*}\text{IPR}_{it-5}) + a'(\mathbf{Z}_{it-5}) + e_{it},$$

where GDPW is real output per worker, IPR proxies patent rights protection and POP country size, OPEN is the Sachs and Warner openness index, and the matrix **Z** contains other controls. All variables are in logs, except for dummies. To alleviate endogeneity

25 This is the case in autarky, but also under free-trade whenever there are countries specialized in the same products.

26 According to Sachs and Warner, an economy is classified as open if satisfies all of the following criteria: (1) non-tariff barriers cover less than 40% of trade (2) average tariff rates are less than 40% (3) any black market premium was less than 20% during the 1970s and 1980s (4) the country is not classified as socialist and (5) the government does not monopolize major exports.

27 Using population to capture a market size effect may be appropriate so long as population is not correlated with other omitted determinants of R&D, such as the cost of innovation. Controlling for human and physical capital is also meant to alleviate concerns about the omission of a direct proxy for R&D costs.

28 This index is based on an assessment of five aspects of patent laws: (1) extent of coverage, (2) membership in international patent agreements, (3) provision for loss of protection, (4) enforcement mechanisms and (5) duration of protection. An alternative, but time-invariant, measure of IPRs is provided by Rapp and Rozek (1990). On the cross-section, the two proxies yield very similar results.

29 Data are available for the following countries: Argentina, Australia, Austria, Belgium, Bolivia, Botswana, Canada, Chile, Colombia, Denmark, Dominican Rep., Ecuador, Finland, France, Greece, Guatemala, Honduras, Hong Kong, Iceland*, India, Iran, Ireland, Israel, Italy, Jamaica, Japan, Kenya, Korea Rep., Malawi, Mauritius, Mexico, Nepal, Netherlands, New Zealand, Norway, Panama*, Paraguay, Peru, Philippines, Portugal, Sierra Leone, Spain, Sri Lanka, Sweden, Switzerland, Syria, Thailand, Turkey, U.K., U.S.A., Venezuela, Zambia, Zimbabwe. An asterisk (*) indicates no Sachs and Warner index available.

Table 1
Descriptive statistics

	IPR	OPEN*	OPEN	KL	HL	POP	GDPW
Panel A. Cross-sectional means (standard deviations)							
1965	2.47	.52	46.69	7848	19.82	26,420	16,953
	(0.59)	(.50)	(25.69)	(7703)	(18.39)	(70,771)	(11,608)
1970	2.52	.51	50.37	10,232	23.51	29,003	18,915
	(.67)	(.50)	(29.52)	(9265)	(19.61)	(78,764)	(12,248)
1975	2.53	.49	57.83	12,997	26.11	31,833	20,917
	(.67)	(.50)	(29.51)	(11,394)	(19.95)	(87,549)	(13,244)
1980	2.69	.52	61.42	15,190	32.72	34,782	21,347
	(.85)	(.50)	(31.38)	(12,781)	(22.09)	(97,354)	(14,101)
1985	2.71	.49	60.69	16,507	35.59	37,821	23,412
		(.50)					
	(.89)		(35.42)	(14,154)	(21.63)	(107,662)	(15,666)
1990	2.75	.70	63.54	18,754	40.26	41,039	25,433
	(.90)	(.46)	(38.14)	(16,336)	(21.99)	(118,867)	(16,960)
Panel B. Correlation (P-values) matrix							
IPR	1						
OPEN*	.413	1					
	(.000)						
OPEN	.197	.247	1				
	(.000)	(.000)					
KL	.561	.523	.105	1			
	(.000)	(.000)	(.060)				
HL	.624	.517	.163	.783	1		
	(.000)	(.000)	(.004)	(.000)			
POP	−.045	−.064	−.309	−.061	−.014	1	
	(.424)	(.263)	(.000)	(.275)	(.801)		
GDPW	.591	.616	.153	.863	.805	−.049	1
	(.000)	(.000)	(.006)	(.000)	(.000)	(.376)	

Note: OPEN* is the Sachs and Warner index of openness. Standard deviations in parentheses in Panel A. *P*-values for the null hypothesis of zero correlation in parentheses in Panel B.

concerns, all regressors are lagged 5 years.[30] According to Eq. (33) the interaction terms of IPR with both OPEN and POP should have a positive sign.

Column 1 of Table 3 reports estimates for the equation above, with **Z** including two important determinants of productivity, physical (KL) and human (HL) capital per worker. Consistently with the model prediction, the coefficient on both interactions is positive and precisely estimated. Note that the coefficient for IPR is negative and significant, suggesting that patent protection lowers income and productivity in autarky. Although this may appear inconsistent with our theory, it may be due to the fact that IPRs protection increases monopoly distortions, an effect the model abstracts from. The negative direct effect of population is instead more difficult to rationalize. Column 2 replicates the estimates in column 1 weighting the observations by country size, as measured by POP. This is an important robustness check, because the mechanism in the paper is probably most relevant for large countries that can affect world incentives to innovate. Moreover, given the wide cross-sectional variation in population, it would be disappointing to find that estimation results are driven by very small countries. It is then reassuring to find that the coefficients of both interactions remain positive and significant. Column 3 restricts the sample to less developed countries only.[31] Despite the loss in the number of observations, the estimate of the interaction term IPR * OPEN is little affected, while the interaction with population become significant at the 12% level only. Returning to the larger sample, column 4 provides an attempt to check whether the IPR protection variable simply acts as a proxy for the quality of institutions. For this purpose, an index of government anti-diversion policies (GADP) and its interaction with openness are added to the estimated equation. This index, taken from Hall and Jones (1999), has been used to measure institutional quality and, like most other proxies of this kind, does not vary over time. Column 4 shows that, as expected, the coefficient for GADP turns out positive and significant, while the previous results are almost unaffected.

Although the pooled OLS regression is a useful way to summarize partial correlations in the data, it may place too much weight on cross-sectional variation and suffer from omitted variables, particularly given the small number of covariates. In this respect, introducing country fixed-effects in the regression, so that $e_{it}=h_i+u_{it}$, has the advantage of controlling for omitted variables that change very little over time and that may be correlated with other regressors, such as institutional and geographical characteristics of countries. However, since this estimator uses only within-country variation, the Sachs and Warner index of openness, with its almost nil time variation in the sample, is inadequate (likewise, the institutional variable GADP cannot be included as it is already captured by the country-effect). The analysis therefore continues using the trade share in GDP as a measure of openness. Before

[30] To avoid losing observations by using lagged values, the dependent variable, available for 1995, is forwarded 5 years in the remainder of the empirical analysis.

[31] In our model, we assumed for simplicity perfect IPRs protection in the North. Yet, the same logic for why IPRs protection increases productivity more in open countries also applies to developed countries, provided that IPRs protection is not perfect. Measures of patent rights vary across all countries in our sample and this justifies their inclusion. Following the World Bank definition, less developed countries included in the sample are: Argentina, Bolivia, Botswana, Chile, Colombia, Dominican Rep., Ecuador, Guatemala, Honduras, India, Iran, Jamaica, Kenya, Korea Rep., Malawi, Mauritius, Mexico, Nepal, Panama, Paraguay, Peru, Philippines, Sierra Leone, Sri Lanka, Syria, Thailand, Turkey, Venezuela, Zambia, Zimbabwe.

Table 2
Conditional correlations

Variable	Conditional on	CORR with GDPW	# Obs.
IPR	OPEN* = 0	.003 (.967)	146
IPR	OPEN* = 1	.748 (.000)	166
OPEN*	IPR < 2.5	.238 (.005)	135
OPEN*	IPR ≥ 2.5	.726 (.000)	177
IPR	POP < mean(POP)	.488 (.000)	254
IPR	POP ≥ mean(POP)	.851 (.000)	70

Note: OPEN* is the Sachs and Warner index of openness. *P*-values for the null hypothesis of zero correlation in parentheses.

moving to the fixed-effects regressions, column 5 replicates the pooled OLS estimates of column 1 with the new trade measure and confirms the previous findings: the two interaction terms are positive and significant.

Columns 6–10 report the results from the panel fixed-effect regressions. Column 6 includes all the right-hand side variables. The interaction term between patent rights and openness is still positive and significant. On the contrary, the coefficient on country size is now very small and not statistically different from zero. This is not surprising, given that population varies mostly across countries (Table 1 shows that the cross-sectional standard deviation of POP is almost three times its mean). It suggests that only the large cross-sectional variation of country size may have a significant impact on the effectiveness of IPRs. Column 7 shows that the inclusion of time dummies does not affect the results. In column 8 we restrict the sample to less developed countries only and find an even higher coefficient for IPR*OPEN. Finally, columns 9 and 10 report the estimates when weighting the observations by country size and after dropping the insignificant size variables, respectively. In both cases, the coefficient on the interaction term between openness and patent rights is found to be positive and statistically different from zero.

A few calculations on the coefficients in Table 3 can help understand the magnitude of the effects and if the estimates across specifications are comparable. Consider first the impact of intellectual property protection. For the average country, columns 1–5–6 imply that a 10% increase of the index of patent rights is associated with an output change of −0.3%, +0.7% and +3.8% respectively. These numbers suggest that, for the average country, gains from stronger IPRs may be uncertain. The situation is different for

Table 3
Openness, IPR and GDP

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	OLS	OLS weighted by POP	OLS LDCs only	OLS	OLS	FE	FE	FE LDCs only	LSDV weighted by POP	FE
IPR	−1.941***	−1.897***	−2.783**	−2.622***	−5.723***	−.407	−.641	−1.767	−.611	−.680*
	(.697)	(.664)	(1.286)	(.749)	(1.568)	(.875)	(.885)	(1.318)	(.848)	(.419)
OPEN	−.437**	−.419**	−.415**	−.368	−.719***	.041	.014	−.048	.042	.013
	(.200)	(.194)	(.201)	(.501)	(231)	(.098)	(.102)	(.137)	(.097)	(.097)
IPR*OPEN	.801***	.784***	.661**	.609***	.556***	.216**	.278**	.409**	.241**	.279***
	(.265)	(.263)	(.273)	(.209)	(.212)	(.105)	(.115)	(.179)	(.111)	(.106)
IPR*POP	.163**	.159***	.223	.224***	.393***	−.005	−.003	.065	.008	
	(.065)	(.060)	(.139)	(.071)	(.089)	(.074)	(.073)	(.109)	(.069)	
POP	−.207***	−.201***	−.245**	−.258***	−.452***	−.013	−.002	−.165	−.019	
	(.700)	(.067)	(.097)	(.077)	(.092)	(.113)	(.134)	(.291)	(.133)	
KL	.400***	.424***	.325***	.343***	.453***	.323***	.354***	.378***	.357***	.354***
	(.075)	(.078)	(.082)	(.078)	(.073)	(.034)	(.038)	(.049)	(.039)	(.038)
HL	.164*	.136	.164*	.160**	.214***	−.037	−.016	−.033	−.013	−.016
	(.084)	(.084)	(.092)	(.079)	(.080)	(.036)	(.036)	(.051)	(.036)	(.032)
GADP				.772***						
				(.282)						
GADP*OPEN				−.053						
				(.296)						
OPEN	Sachs and Warner	Sachs and Warner	Sachs and Warner	Sachs and Warner	Trade/GDP	Trade/GDP	Trade/GDP	Trade/GDP	Trade/GDP	Trade/GDP
R-squared	.83	.84	.68	.85	.82	.58	.61	.58	.99	.61
# Obs.	306	305	173	300	318	318	318	179	317	318
Time effects	No	No	No	No	No	No	Yes	Yes	Yes	Yes

Note: All variables, except dummies, are expressed in logs. RHS variables are lagged (5 years). Standard errors (robust, in LS regressions) are reported in parenthesis. Constant not reported. *, ** and *** indicate significance at 10, 5 and 1% level. Data sources: Ginarte and Park (1997) for IPR, Hall and Jones (1999) for GADP, Sachs and Warner (1995) for the dummy indicator OPEN, Barro and Lee (2001) for HL (share of population above 25 years with some secondary education), PWT 6.0 for the other variables.

trading economies: with openness one standard error above the sample mean, the reaction of output becomes +3.7%, +4% and +5.1% respectively. Conversely, for countries closed to trade (one standard deviation below the sample mean) the effect may be negative: −4.3%, −2.5% and +2.5%. Similarly, according to columns 1–5–6, a 10% increase of the openness index in the average country is associated with an output change of +2.9%, −2.1% and +1.5%, respectively. In countries with IPRs one standard error above the sample mean, the positive effect of trade is instead more pronounced: +5.5%, −0.3% and +2.2%. Finally, for countries with IPRs one standard error below the sample mean, the effect of trade becomes small or even negative: +0.3%, −3.9% and +0.8%. Although the variability of estimates across specifications is not unacceptably high, given that coefficients come from regressions using very different trade measures and estimation techniques, it makes it difficult to draw sharp empirical conclusions. However, these numbers indicate that open and perhaps large economies might benefit from stronger patent laws. It may thus suggest that the process of trade liberalizations in India and China could be more beneficial if accompanied by a tightening of IPRs.

We conclude this section with a word of caution. Although the data provide some support to the model, this empirical analysis has important limitations. For example, the existence of reverse causality cannot be ruled out.[32] Moreover, the link between the variables in our two-country model and the cross-country panel data used here is somewhat imperfect and some of the results in Table 3 cannot be immediately rationalized with our theory. For these reasons, these findings should be taken as suggestive. Nonetheless, we hope that they may stimulate more extensive empirical work aimed at testing alternative mechanisms linking trade and IPRs policies.

3.2. North–South trade and the pattern of R&D

The goal of this section is to test whether North–South trade affects the direction of technical progress and thus the industry pattern of R&D investment. According to the model, in a period of growing North–South trade, the innovative effort of advanced countries should become more specialized towards the sectors in which those countries have a comparative advantage. Using data on a panel of US manufacturing industries, we test whether an increase in import penetration from low-wage, low-IPRs countries is indeed followed by a drop in R&D investment. The focus on US sectors is partly dictated by data availability, but is also justified by the fact that the US economy represents the world leader in new technologies.

The NSF Survey of Industry Research and Development (IRIS) provides annual data on R&D expenditure at the 2-digit SIC industry level for the period 1972–1996.[33] We restrict the analysis to manufacturing sectors only, since they are more likely to be affected by trade. Annual data on industry-level output, proxied by the total value of shipments, factor employment, investment, capital stocks and costs are available for all US 4-digit SIC manufacturing industries from the NBER Manufacturing Industry Database, spanning the period 1958–1996. For the same set of 4-digit SIC manufacturing industries, trade data can be used to build two different measures of import penetration: the total import value divided by domestic absorption and the import value proceeding from low-wage countries only, divided by domestic absorption. This latter variable is taken from Bernard et al. (2006) and will be used to measure North–South trade at the industry level. To build it, Bernard et al. (2006) define low-wage countries as those with a per capita GDP less than 5% of the US level. The set of countries representing the South according to this criterion appears quite reasonable for our purposes: it is relatively stable over time, it accounts for roughly 50% of world population and it includes the largest developing countries with weak IPRs protection that are central for the analysis (i.e., China, India, Pakistan and Bangladesh, whose population accounts for 79% of the entire group).[34]

With this data, we can test if import penetration from the South affects the pattern of R&D investment in the US economy, as the model predicts. To do so, we regress the series of R&D expenditure on the two measures of import penetration and a number of control variables. Since R&D data is available for fifteen 2-digit industries only, we first aggregate the data at the 4-digit level accordingly. The fifteen industries are listed in Table 5, together with some descriptive statistics that will be discussed later on.

We then perform a number of estimates of the following R&D equation:

$$\text{R\&D}_{it} = \alpha + \beta \text{IMP}_{it} + \gamma \text{IMP\_}S_{it} + \delta' \boldsymbol{X}_{it} + \eta_i + \varepsilon_{it},$$

where i indicates the industry observed in year t, IMP denotes total import penetration and IMP_S import penetration from low-wage countries, henceforth the South. $\boldsymbol{X}$ is a vector of control variables (output, investments, capital stock and the share of skilled workers in total employment), η_i is an industry-specific component which is constant over time, and ε_{it} is the iid error term.[35] The model predicts that investments in R&D should drop in sectors where import penetration from the South is higher, and is therefore supported by negative estimates of γ.

The results of the estimation are reported in Table 4. The measure of R&D in use as dependent variable varies throughout the columns. In columns 1 and 2, the dependent variable is the log of R&D expenditure. The coefficient for import penetration from the South, negative and significant, is in line with the prediction of the model. Interestingly, the coefficient for overall imports is instead positive, but smaller in absolute value than the other one. Thus, while overall import penetration tends to increase

[32] Despite the use of lagged variables, endogeneity concerns may remain. Unfortunately, IV strategies relying on historical and geographical instruments have little hope to solve the problem because the typical instruments have been shown to be weak to identify separately the effects of trade and institutions. The presence of interaction terms and the need to distinguish IPR protection from other institutional variables make the problem much worse.

[33] In some cases, data are for groups of 2-digit SIC industries.

[34] Low wage countries in the dataset are: Afghanistan, Albania, Angola, Armenia, Azerbaijan, Bangladesh, Benin, Bhutan, Burkina Faso, Burundi, Cambodia, Central African Republic, Chad, China, Comoros, Congo, Equatorial Guinea, Eritrea, Ethiopia, Gambia, Georgia, Ghana, Guinea, Guinea-Bissau, Guyana, Haiti, India, Kenya, Lesotho, Madagascar, Malawi, Maldives, Mali, Mauritania, Moldova, Mozambique, Nepal, Niger, Pakistan, Rwanda, Samoa, Sao Tome, Sierra Leone, Somalia, Sri Lanka, St. Vincent and Grenadines, Sudan, Togo, Uganda, Vietnam, Yemen.

[35] Following a standard practice, we proxy skilled workers with non-production workers.

Table 4
North–South trade and R&D at the industry level (fixed-effects)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	FE	FE	FE	FE	LSDV weighted by Y	FE 2-period lags	LSDV	LSDV 2-period lags
	Log(R&D)	Log(R&D)	R&D/Y	R&D/Y	R&D/Y	R&D/Y	R&D/Y imputed	R&D/Y imputed
Import	11.486***	1.396**	.092***	−.046	.056*	−.052	.0039***	.0031***
	(1.088)	(.703)	(.021)	(.029)	(.034)	(.031)	(.0007)	(.0008)
Import (South)	−35.426***	−12.647***	−.937***	−.727***	−.597***	−.564**	−.0047***	−.0038***
	(10.266)	(4.927)	(.201)	(.21)	(.205)	(.264)	(.0008)	(.0009)
Log(*Y*)		.529***		.005	.003	.01***	.0008***	−.0001
		(.123)		(.005)	(006)	(.004)	(.0002)	(.0002)
Skill		−1.476		.138***	.166***	.049		
		(1.055)		(.045)	(.045)	(.043)		
Log(*I*)		−.153**		−.011***	−.006	−.005		
		(.078)		(.003)	(.004)	(.003)		
Log(*K*)		1.096***		.016**	.007	.009		
		(.157)		(.007)	(.008)	(.007)		
Time dummies	No	Yes	No	Yes	Yes	Yes	Yes	Yes
R-squared	.48	.91	.09	.29	.97	.22	.98	.98
# Obs.	259	259	259	259	259	231	8981	8314
# Industries	15	15	15	15	15	15	385	385

Note: All variables are yearly observations between 1972 and 1996. Regressions in columns (1)–(6) are performed on US 2-digit industry-level data. Regressions in columns (7) and (8) are weighted by the share of import penetration from the South, and refer to US 4-digit industries. The series of imputed R&D shares is obtained from equation R&D_share = −.036 + .134(Skill) − .6 * 10^{-6} (I) + .2 * 10^{-8}(K) + φ(industry) (R^2 = .93), estimated on 2-digit industry-level data. Standard errors in parentheses. ***,**,* = significant at the 1, 5 and 10% levels, respectively. Data sources: NSF-IRIS for R&D expenditure at 2-digit industry level, Bernard et al. (2006) for 4-digit industry-level import penetration data, and NBER for the other series.

investment in innovation, the net effect of import penetration from low-wage countries is negative. Column 2 confirms these results when controlling for industry output, skilled labor employment, investment, capital stock and time effects.

Starting from column 3, we use R&D expenditure as a share of industry output as dependent variable. In this case, the coefficient γ captures the variation in R&D that is not explained by proportional changes in the size of a sector, which may be in turn negatively correlated with import penetration from the South. This means that the regressions in columns 3–8 are more demanding on the prediction of the model. Nevertheless, the estimates of γ remain negative and significant across all specifications. Column 4 shows that the negative estimate for import penetration from the South is robust to controlling for time effects and other covariates of R&D. In column 5 we estimate the same equation as in column 4 weighting observations by industry size. The coefficients confirm that the sign and significance of γ are not driven by particularly small sectors. As in all empirical analyses using linear models, concerns of reverse causality may arise. In particular, it may well be that lowering R&D effort makes import penetration from imitating countries easier. Unfortunately, there are not many tools we can use to tackle this issue, given that the limited number of sectors invalidates cross-sectional analysis. Nevertheless, as an attempt to show that the estimates we obtained are not overly driven by reverse causation, we regress the R&D share on 2-year lagged values of the RHS variables. If causality runs from R&D investment to trade only, we should observe a much smaller (virtually zero) coefficient for the lag of import penetration from the South. On the contrary, in column 6 we still obtain a negative and significant estimate of γ, with a coefficient slightly smaller in size. This suggests that reverse causation, even if present, does not seem to be very strong.[36]

The results in columns 1–6 refer to fifteen industries, observed between 1972 and 1996. If we could expand the R&D series from 2-digit to 4-digit industries, we would be able to consider around 400 manufacturing sectors, so that our estimates would convey much more information and would be more general. Although we do not have such data, we can nonetheless exploit the high correlation between R&D and other variables in the dataset (for instance, the simple correlation between R&D share and skill intensity is 0.62) to perform a final exercise that would give us a sense of whether the previous findings are likely to be robust at the 4-digit level. To do so, we first estimate the following linear equation for R&D shares on 2-digit industry data:

$$\text{R\&D\_share}_{it} = -0.036 + 0.134(Skill_{it}) - 6*10^{-7}(I_{it}) + 2*10^{-9}(K_{it}) + \varphi'(ind) + \xi_{it},$$

where ind is a matrix of industry dummies, ξ_{it} is an iid error and R^2 = 0.93. We then use the estimated coefficients to impute R&D share data for the 4-digit industries as:

$$\text{R\&D\_share}_{j(i)t} = -0.036 + 0.134\left(Skill_{j(i)t}\right) - 6*10^{-7}\left(I_{j(i)t}\right) + 2*10^{-9}\left(K_{j(i)t}\right) + \varphi_i,$$

where j is a 4-digit industry of the 2-digit sector i. With the imputed data at hand, column 7 reports estimates for the equation:

$$\text{R\&D\_share}_{jt} = \tilde{\alpha} + \tilde{\beta}\text{IMP}_{jt} + \tilde{\gamma}\text{IMP\_}S_{jt} + \tilde{\delta}' log\left(Y_{jt}\right) + \bar{\eta}_j + v_t + \tilde{\varepsilon}_{jt}.$$

[36] The reverse exercise of regressing import penetration from the South on lagged R&D investment yields a much smaller (albeit significant) coefficient. This is again evidence that reverse causation does not seem strong.

Table 5
R&D shares, import penetration and the path of R&D (1972–1996)

Industry	SIC 87 Code(s)	% R&D share 1972	% Skill 1972	% Import 1972	% Import (South) 1972	Δ(%Import) 1972–96	Δ(%Import South) 1972–96	l% Δ(R&D) (predicted)
Food, kindred, and tobacco products	20, 21	0.21	30.14	4.06	0.35	5.75	0.41	−9.35
Textiles and apparel	22, 23	0.11	12.35	7.25	0.60	24.16	8.17	−85.84
Lumber, wood products, and furniture	24, 25	0.18	14.58	6.08	0.16	5.19	1.18	−24.59
Paper and allied products	26	0.67	21.33	5.09	0.02	3.94	0.84	−18.31
Chemicals and allied products	28	3.27	37.22	5.95	0.32	7.19	0.13	−3.17
Petroleum refining and extraction	13, 29	1.74	29.08	4.37	0.02	7.28	0.42	−9.63
Rubber products	30	1.74	21.44	4.41	0.01	13.16	2.71	−47.79
Stone, clay, and glass products	32	0.88	20.84	7.59	0.05	8.72	1.55	−31.02
Primary metals	33	0.47	19.26	10.06	0.17	12.93	1.42	−28.90
Fabricated metal products	34	0.50	23.14	3.81	0.02	7.28	0.70	−15.47
Machinery	35	3.25	30.63	6.22	0.00	22.20	1.18	−24.62
Electrical equipment	36	10.06	26.95	5.49	0.01	26.33	3.65	−58.31
Transportation equipment	37	[a]	27.51	10.82	0.00	11.75	0.33	−7.20
Professional and scientific instruments	38	3.84	40.75	8.61	0.02	17.40	1.69	−33.28
Other manufacturing industries	27, 31, 39	0.89	30.75	12.43	0.23	32.13	12.97	−95.51

Note: “Other manufacturing industries” include “printing, publishing and allied”, “leather and leather products”, and “miscellaneous manufacturing” industries. The predicted variation in R&D expenditure between 1972 and 1996 is computed using the estimates in column (1) of Table 4, and assuming that only import penetration from the South has changed: $\Delta\log(\text{R\&D})=(11.486-35.426)*\Delta(\text{Import South})$. [a]Data on R&D for the “transportation equipment” industry are available from 1986 hence the initial R&D share is not reported.

Notice that now we can only control for total industry output because the other variables have been used to impute the R&D shares. Moreover, since around 60% of the industry-years have virtually no import penetration from the South, we weight observations by the share of industry imports sourced from low-wage countries. These new estimates confirm the previous pattern, that the overall effect of import from the low IPR countries on R&D shares is negative and significant. Finally, column 8 replicates the exercise of column 6, with analogous results: import penetration from the South reduces R&D shares even with a 2-year lag.

So far, the analysis suggests that import penetration from the South has a negative and significant impact on R&D investment. The final step is to show that this effect is quantitatively large. This is done in Table 5, reporting a number of interesting industry statistics for the years 1972–1996, together with the predicted impact of imports from the South on the level of R&D expenditure over the period. For each of the fifteen 2-digit industries, the table reports in the first columns the relevant SIC 87 codes, the R&D share, skilled workers over total employment and import penetration (in percentage points) both overall and from low-wage countries in 1972. The next two columns show the percentage points increase of the two import measures. Note that while imports from the South were close to zero in almost all industries at the beginning of the sample, by the end of the period they have grown large in some sectors (up to more than 8% and 13% in Textiles and Other Manufacturing, respectively). The last column reports the percentage variation in R&D expenditure predicted by the increase in import penetration from the South over the 25-year sample, using the estimates of column 1 in Table 4 and assuming that all other variables (included import penetration from the other industrialized countries) remained constant. The predicted impact of North–South trade on the industry pattern of R&D is quite dramatic. All else equal, Textile and Other Manufacturing Industries (including Leather and Toys), where imitation is easy and the comparative advantage of the South is strong, would have suffered an 85 and 95% drop in R&D investment, respectively. On the contrary, R&D in sectors where the comparative advantage of the North is strong, like Chemicals and Transportation Equipment (including Motor Vehicles and Aircrafts) would barely be affected.

3.3. Revisiting the literature

Some of the results in this paper stand in contrast with part of the existing literature. For example, in the trade models of Helpman (1993) and Dinopoulos and Segerstrom (2004) stronger IPRs in the South can lower the incentives to innovate and increase the North–South wage differential. It is thus important to discuss the origin of these differences and the evidence in favor of the various approaches. The reason why IPRs protection can discourage innovation in Helpman (1993) and Dinopoulos and Segerstrom (2004) is that imitation in the South can free up Northern labor from production that can be employed in the R&D sector. Depending on parameter values and specific assumptions, this effect may or may not dominate the negative impact of imitation on profits. Yet, it is unclear which outcome is more realistic: although mixed, the evidence surveyed in Falvey et al. (2006) seems to suggest that IPRs protection is more likely to stimulate innovation, rather than the opposite. Moving from this observation, in the present paper the tension is resolved in favor of a positive link between IPRs and innovation by assuming that R&D does not directly require labor, as in the convenient lab-equipment specification of endogenous growth models.

Second, in Helpman (1993) and Dinopoulos and Segerstrom (2004) stronger IPRs protection in the South slows down technology transfer, implying a higher share of production located in the North and lower Southern wages. This is the case because in those models technology transfer happens through imitation only. On the contrary, Lai (1998) and Yang and Maskus (2001) have shown that stronger Southern IPRs may speed up technology transfer through FDI and licensing. While the evidence on this issue is still inconclusive, several studies reported in Falvey et al. (2006) are consistent with the latter view. An informal look at the data also suggests the relocation of production to the South to have increased at the same time as many developing countries were strengthening IPRs protection. Thus, the approach of this paper, according to which IPRs protection can be instrumental in attracting technologies (and economic activity) seems plausible.

The results of this paper are also consistent with a number of observations. The empirical findings in Sections 3.1 and 3.2 provide some support to the channel emphasized in this paper. Moreover, the result that IPRs protection might be more effective in open countries may help explain the positive correlation between measures of IPRs protection and trade openness documented in Table 1 and in part of the empirical literature. The model also suggests that trade opening may trigger a transition in which innovation is mostly directed towards Northern sectors and, at the same time, economic activity is relocated from the North to the South. Evidence of skill-biased technical change and outsourcing seems broadly consistent with these predictions. Finally, the model suggests that market integration may have increased the income gap between poor and rich nations. While the impact of trade on different countries is a controversial issue, there are empirical works showing that trade may have contributed to a widening of the cross-country income distribution.[37] In conclusion, while existing models have illustrated important aspects of the complex relationship between trade, IPRs and innovation, the complementary approach taken in this paper seems at least equally plausible and appears to be useful in explain a number of empirical observations.

4. Concluding remarks

This paper has presented a simple model where market integration may amplify income differences between rich and poor countries and may lower the world growth rate. Rather than raising warnings against globalization, the analysis has identified a specific market failure, weak protection of intellectual property in developing countries, under which trade can have undesirable effects. Its main lesson is that, in a world of integrated economies, profits from innovations play a crucial role in directing technical progress towards the needs of all countries and in sustaining long-run growth. Even though the analysis hints at potential gains from global IPRs regulations, it abstracts from the fact that enforcing worldwide standards may be costly for LDCs and that the profits from their markets may fail to provide the proper incentives for such reasons as high transaction costs or expropriation risk. Given these imperfections, promoting research aimed at the needs of the less developed countries appears to be a key element for reducing income differences and fostering world economic growth.

Before concluding, it is worth to mention some limitations and possible extensions of this paper. The first is the lack of welfare analysis. Although the main goal was to illustrate a novel mechanism through which North–South trade may affect relative wages and economic growth, it would be desirable to study its effect on welfare as well. Unfortunately, such an exercise poses serious difficulties.[38] Second, the paper is built on the hypothesis that ideas can flow rapidly across borders and technological knowledge (but not productivity) is the same across countries. While this view is not uncommon and has empirical merits (see, for instance, Acemoglu and Zilibotti, 2001), it is nonetheless possible that trade itself contributes to technology transfer between countries.[39] Third, infringements of intellectual property rights and firms' structure have been modeled in a stylized way. As a consequence, the model is silent on the role played by multinationals or other organizational forms of production. Finally, we have assumed that Southern countries can only imitate, while nowadays countries like China and India also invest in innovation.[40] Incorporating these elements into the analysis would certainly improve our understanding of the complex interactions between innovation, imitation and growth in a global economy and seems a fruitful direction for future research.

Appendix A

A.1. Optimality of technologies

Consider first the case of no IPRs protection in S, ($\theta=0$). The optimal sectoral profile of $N(i)$ is the solution to the following program:

$$Max_{\{N(i)\}} Y_N = L_N \left\{ \int_0^1 [N(i)\phi_N(i)]^{\sigma} \mathrm{d}i \right\}^{1/\sigma} \quad \text{s.t.} \quad \int_0^1 N(i)\mathrm{d}i = \overline{N},$$

where $\overline{N}$ is a positive constant. The first order conditions (FOCs), $\forall i \in [0, 1]$, are:

$$L_N \left\{ \int_0^1 [N(i)\phi_N(i)]^{\sigma} \mathrm{d}i \right\}^{\frac{1-\sigma}{\sigma}} [N(i)\phi_N(i)]^{\sigma-1} \phi_N(i) = \lambda$$

[37] See, for example, Beaudry et al. (2005) and DeJong and Ripoll (2006).

[38] In this model, welfare comparison across trade regimes would tend to be arbitrary because it is hard to measure comparative advantage and thus the gains from trade. Moreover, a more realistic description of IPRs would be required. Finally, the analysis would be complicated by the need to compute welfare along non-trivial transitional dynamics. A way to circumvent these problems could be to use a simpler two-good model along the lines of Saint-Paul (2008).

[39] Evidence on the role of trade in promoting technology transfer is mixed. See Keller (2004) for a survey.

[40] Innovation by the South need not change the main results of the paper, provided that innovators are unable to fully appropriate the monopoly rent from selling machines in the South market. However, given that profits would stay in the South, local innovation would certainly make governments of LDCs more willing to protect IPRs.

where λ is the Lagrange multiplier associated to the constraint. Taking the ratio of any two FOCs and using $A_N(i) = N(i)\,\phi_N(i)$ yields Eq. (14). This proves that the sectoral profile of the endogenous technology maximizes Northern output and wage and hence it is optimal for the North.

Consider now the case of imperfect protection of IPRs in S, $(\theta \neq 0)$.

$$Max_{\{N(i)\}} Y_N + \theta Y_S = L_N \left\{ \int_0^1 [N(i)\phi_N(i)]^\sigma \mathrm{d}i \right\}^{1/\sigma} + \theta L_S \left\{ \int_0^1 [N(i)\phi_S(i)]^\sigma \mathrm{d}i \right\}^{1/\sigma}$$

$$\text{s.t.} \quad \int_0^1 N(i)\mathrm{d}i = \bar{N}$$

the FOCs for a maximum are, $\forall i \in [0, 1]$:

$$L_N \left\{ \int_0^1 [N(i)\phi_N(i)]^\sigma \mathrm{d}i \right\}^{\frac{1-\sigma}{\sigma}} [N(i)\phi_N(i)]^{\sigma-1}\phi_N(i) + \theta L_S \left\{ \int_0^1 [N(i)\phi_S(i)]^\sigma \mathrm{d}i \right\}^{\frac{1-\sigma}{\sigma}} [N(i)\phi_S(i)]^{\sigma-1}\phi_S(i) = \lambda$$

where λ is the Lagrange multiplier associated to the constraint. Using Eq. (9) and solving for $N(i)$:

$$N(i) = \left[\frac{L_N \phi_N(i)^\sigma (w_N)^{1-\sigma} + \theta L_S \phi_S(i)^\sigma (w_S)^{1-\sigma}}{\beta\lambda} \right]^{1/(1-\sigma)}.$$

Comparing this condition with Eq. (20) in the text shows that the sectoral distribution of the endogenous technology maximizes a weighted sum of Northern and Southern aggregate output, with a weight of θ on the South. As $L_N/(\theta L_S) \to 0$, technologies maximize w_S, whereas as $L_N/(\theta L_S) \to \infty$ they maximize w_N.

A.2. Properties of the wage ratio in autarky

To show that the North–South wage ratio in autarky is bounded by $\max\{\phi_N(i)/\phi_S(i)\} = \phi_N(0)/\phi_S(0)$, first note that $\partial\omega/\partial\phi_N(i) > 0$ and $\partial\omega/\partial\phi_S(i) < 0$. Therefore, by construction:

$$\omega = \left[\frac{\int_0^1 \phi_N(i)^{\sigma/(1-\sigma)} \mathrm{d}i}{\int_0^1 \phi_N(i)^{\sigma^2/(1-\sigma)} \phi_S(i)^\sigma \mathrm{d}i} \right]^{1/\sigma} \leq \left[\frac{\int_0^1 max\phi_N^{\sigma/(1-\sigma)} \mathrm{d}i}{\int_0^1 max\phi_N^{\sigma^2/(1-\sigma)} min\phi_S^\sigma \mathrm{d}i} \right]^{1/\sigma} = \frac{\phi_N(0)}{\phi_S(0)}.$$

A.3. The growth rate under free-trade

Take the formula for the instantaneous rent appropriated by a technology monopolist in the North:

$$\pi_N(i) = \bar{\pi} = \beta(1-\beta)p(i)^{1/\beta}\phi_N(i) \frac{L_N A_N(i)^\sigma}{\int_0^z A_N(v)^\sigma \mathrm{d}v}.$$

Note that, along the balanced growth path, $\bar{\pi}$ is equalized across sectors and countries, with $\pi_N(i) = \theta\pi_S(j)$. Use Eq. (7) to substitute for w_N and rearrange to get:

$$p(i)^{1-\epsilon} = \left[\frac{\beta(1-\beta)}{\bar{\pi}} \frac{\phi_N(i) L_N A_N(i)^\sigma}{\int_0^z A_N(v)^\sigma dv} \right]^\sigma.$$

Use $A_N(j) = A_N(i)\left[\frac{\phi_N(j)}{\phi_N(i)}\right]^{1/(1-\sigma)}$ to substitute $A_N(i)^\sigma = \frac{\phi_N(i)^{\sigma/(1-\sigma)} \int_0^z A_N(j)^\sigma dj}{\int_0^z \phi_N(j)^{\sigma/(1-\sigma)} dj}$. Integrate over the interval [0, 1], use Eq. (3) and rearrange:

$$\bar{\pi} = \beta(1-\beta) \left\{ (L_N)^\sigma \left[\int_0^z \phi_N(i)^{\frac{\sigma}{1-\sigma}} \mathrm{d}i \right]^{1-\sigma} + (\theta L_S)^\sigma \left[\int_z^1 \phi_S(i)^{\frac{\sigma}{1-\sigma}} \mathrm{d}i \right]^{1-\sigma} \right\}^{1/\sigma}. \tag{34}$$

Finally, use Eq. (26) to substitute for $\int_z^1 \phi_S(i)^{\sigma/(1-\sigma)} di$. The Euler equation $g = r - \rho$ together with the free-entry condition $\bar{\pi} = r\mu = r(1-\beta)\beta$ yield Eq. (27) in the text.

A.4. The model without scale effects

We now briefly show how the scale effect, e.g., the positive dependence of the long-run growth rate on the level of population, can be removed without changing the main results. Scale-invariant models of innovation have been developed by Jones (1995), Segestrom (1998) and Young (1998), among others. Here we follow Jones (1995) and Segestrom (1998) in combining population growth with increasing complexity in R&D. We begin by considering the North in isolation. Population grows exponentially at the exogenous rate $n>0$ (we shall assume that this is also the population growth rate of the South). Households are modeled as dynastic families that maximize:

$$U=\int_0^{\infty} e^{-(\rho-n)t} log c(t) \mathrm{d}t,$$

where $c(t)$ is per capita consumption and $\rho-n>0$. As it is well-known, the dynamic optimization problem of the household subject to the usual budget constraint leads to the familiar Euler equation for consumption growth Eq. (16).

To remove the scale effect, we modify the R&D technology by assuming that the cost of innovation grows with the stock of technical knowledge:

$$\mu(i)=\mu=\beta(1-\beta)N^{\lambda}, \tag{35}$$

where $N=\int_0^1 N(i)di$ and $\lambda>0$. This assumption captures the idea that technology becomes more complex as knowledge expands.[41] Along the balanced growth path, two conditions must hold. First, the owner of a patent with value $V(i)$ must be indifferent between running the firm and investing its value:

$$\frac{\pi(i)}{V(i)}+\frac{\dot{V}(i)}{V(i)}=r. \tag{36}$$

That is, the dividend rate $\pi(i)/V(i)$ plus the capital gain $\dot{V}(i)/V(i)$ exactly meet the rate of return on investment. Second, free-entry requires the cost of innovation to be equal to its value:

$$V(i)=V=\mu. \tag{37}$$

Substituting Eq. (35) and deriving Eq. (37) with respect to time we obtain:

$$\frac{\dot{V}}{V}=\lambda g, \tag{38}$$

where g is the growth rate of N. Substituting Eqs. (37), (38) and (16) into Eq. (36) yields:

$$\pi=\mu[g(1-\lambda)+\rho]. \tag{39}$$

As in the basic model with $n=\lambda=0$, the cross-section of technology is pinned down by equalizing instantaneous profits in all sectors, still yielding Eqs. (14) and (15). Deriving Eq. (39) with respect to time and noting that π grows at the rate n (see Eq. (15)) we find that, as usual in this class of models, long-run growth depends on population growth:

$$g=\frac{n}{\lambda}. \tag{40}$$

The expressions for instantaneous profits, wages and the cross-section of technology, $N(i)$, are instead unaffected by population growth. This implies that, once trade is allowed, Proposition 1 is still valid.

Given that the long-run growth rate now depends on n and λ, but not on θ, Proposition 2 takes instead a different form: IPR protection does not affect the long-run growth rate anymore, but it affects *when* and *how* the economy reaches the balance growth path. Preserving the spirit of Proposition 2, a move from autarky to free-trade can trigger a prolonged period of low growth. This can be seen, for example, comparing the ratio N^{λ}/L_N (constant in the long run) in autarky and free-trade when $\theta=0$. In the case of no trade and $\theta=0$, this ratio can be computed equalizing Eqs. (15) to (39) and using Eqs. (35) and (40):

$$\frac{N^{\lambda}}{L_N}=\frac{\lambda\left[\int \phi_N(i)^{\frac{\sigma}{1-\sigma}}\mathrm{d}i\right]^{\frac{1-\sigma}{\sigma}}}{n(1-\lambda)+\lambda\rho}.$$

From any initial condition, N^{λ}/L_N converges to a positive level given above.[42]

When trade in goods is allowed, the formula for the instantaneous profits appropriated by an innovator is instead Eq. (34). Setting this equal to Eq. (39) and using Eqs. (35) and (40), the long-run, free-trade ratio N^{λ}/L_N is found to be:

$$\frac{N^{\lambda}}{L_N}=\frac{\lambda\left\{\left[\int_0^z \phi_N(i)^{\frac{\sigma}{1-\sigma}}\mathrm{d}i\right]^{1-\sigma}+\left(\frac{\theta L_S}{L_N}\right)^{\sigma}\left[\int_z^1 \phi_S(i)^{\frac{\sigma}{1-\sigma}}\mathrm{d}i\right]^{1-\sigma}\right\}^{1/\sigma}}{n(1-\lambda)+\lambda\rho}. \tag{41}$$

Note that, as θ approaches zero, z falls to zero and so does the right-hand side of Eq. (41): $\lim_{\theta\to 0}(N^{\lambda}/L_N)=0$. But then, for the economy to reach asymptotically this long-run equilibrium, a prolonged period of relatively low growth is required: for N^{λ}/L_N to fall after trade opening, g must be lower than the long-run growth rate n/λ.

[41] Note that the cost of innovation in sector i grows with average N and not just with the measure of technology in sector i. This assumption is not crucial, but has the important advantage of keeping the cost of innovation μ equalized across sector, as in the model in the main text. With this assumption, the comparison between the model with and without scale effects is most transparent.

[42] The denominator is always positive given the assumption $\rho-n>0$.

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