Tariffs and Technological Hegemony

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Abstract

We provide a theory connecting trade policies to innovation and technological hegemony, based on the notion that high-tech clusters generate technological rents for the countries hosting them. We show that tariffs on high-tech imports may be used to steal technological rents from the rest of the world, by redirecting innovation activities from foreign to domestic firms. This strategy may lead to welfare gains, which however come at the expense of even larger welfare losses in the rest of the world. Tariffs may backfire even for the country imposing them if they are not well designed, or if the rest of the world retaliates.

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1 Introduction

With the advent of the Trump administration, the United States has declared a trade war against the rest of the world. The underlying hope is that import tariffs will increase the competitiveness of US firms, and reduce the US trade deficits (Miran, 2024). Whether these goals will be attained, however, is far from clear (Obstfeld, 2025). Moreover, this trade war has caught the rest of the world off guard. Take the case of the European Union, which has chosen not to retaliate against the tariffs imposed by the United States. Some commentators have seen this move as a humiliating defeat. Others have argued that retaliating would have only amplified the losses that US tariffs will inflict on the EU.

We contribute to this debate by providing a theory connecting trade policies to innovation and technological hegemony. The central notion of our theory is that high-tech clusters, that is clusters of firms investing heavily in innovation, generate technological rents for the countries hosting them. We show that tariffs on high-tech imports may be used to steal technological rents from the rest of the world, by redirecting innovation activities from foreign to domestic firms. This strategy may lead to welfare gains, which however come at the expense of even larger welfare losses in the rest of the world. Tariffs may backfire even for the country imposing them if they are not well designed, or if the rest of the world retaliates.

We derive these insights using an endogenous growth model of the global economy. There are two countries: home and foreign. Both countries produce high-tech (intermediate) goods.[1] High-tech firms sell their products on the global market, and earn a substantial part of their profits from exports. Moreover, high-tech firms invest in innovation to improve the quality of their products. As in standard endogenous growth models, innovation activities generate geographically-localized knowledge spillovers.[2] Hence, high-tech firms benefit the hosting country not only because they are highly profitable, but also because of the positive knowledge spillovers that they emanate to other domestic firms. Some examples of the high-tech firms that we have in mind are the Big Tech firms located in the Silicon Valley and the EU pharmaceutical industry.

The other key element of our theory is that innovation requires the use of specialized inputs, which we call innovation goods. Innovation goods are in limited supply in the global economy and geographically mobile. Two good examples are researchers and venture capital, which are key inputs in the innovation process. Importantly, due to the presence of knowledge spillovers, suppliers of the innovation goods capture only part of the rents generated by innovation.

Together, these two elements imply that countries have an incentive to compete for technological

[1] We define high-tech goods as the products of industries in which investments in R&D and other intangible assets play an important role. Hence our high-tech goods category not only includes high-tech manufactured goods, but also services and intellectual properties. The importance of high-tech goods in international trade is substantial. For instance, using the OECD definition of high-tech goods (Galindo-Rueda and Verger, 2016), in 2023 exports of high-tech goods represented between 50% and 60% of total goods exports for the United States, European Union and China.

[2] The notion that investments in innovation generate knowledge spillovers is a cornerstone of the endogenous growth literature (Romer, 1990; Aghion and Howitt, 1992). Audretsch and Feldman (1996) is a classic reference documenting the importance of geographical proximity for knowledge spillovers. Moretti (2021) shows that joining high-tech clusters fosters inventors' productivity.

hegemony, that is to become net importers of innovation goods. The reason is that the suppliers of the innovation good are paid only the private return to innovation, which is lower than its social return. From a national perspective, importing innovation goods thus generates technological rents, equivalent to the spread between the social and private return to investing in innovation. The technological hegemon runs trade deficits in innovation goods, and thus earns an exorbitant technological privilege in the form of high technological rents.

Private firms do not fully internalize the impact of their investment decisions on the technological rents earned by their host country. Policy interventions by national governments that attract innovation goods and technological rents may thus increase national welfare. We show that, under certain circumstances, import tariffs on high-tech goods may serve this purpose. Intuitively, import tariffs reduce the profits earned by the foreign high-tech sector. The result is that innovation activities by foreign firms decline, and innovation goods flow toward the country imposing the tariffs.[3] Over time, higher investment in innovation generates technological rents and income gains.

But tariffs have also negative effects. First, tariffs trigger a drop in the imports of foreign high-tech intermediate goods, depressing domestic productivity.[4] These efficiency losses are concentrated in the short run, that is before the impact on productivity of higher investment in innovation by domestic firms has materialized. Import tariffs on high-tech goods have thus an ambiguous impact on national welfare, depending on whether the long-run gains from higher technological rents outweigh the productivity losses suffered in the short run.

Moreover, tariffs on high-tech goods cause income and welfare losses in the rest of the world, because they depress the export revenue earned by foreign high-tech firms. This loss gets amplified over time, since lower investment in innovation further erodes the profits earned by high-tech firms. In fact, we show that tariffs - while they may bring welfare gains to the country imposing them - depress global welfare.

What if the rest of the world has the option to retaliate? If the gains from earning technological rents are moderate, the world experiences a strategic trade war. In this scenario, one country imposes large tariffs on imports of high-tech goods. The tariffs are large, because they serve the strategic purpose of discouraging retaliation by the other country. The world thus falls in a unilateral trade war, in which one country disrupts international trade to boost its technological rents. If the technological rents are sufficiently large, instead, the world falls prey of a full-blown trade war. In this case, both countries impose very high tariffs to defend their domestic high-tech sector and prevent the loss of technological rents. The result is a drop in global output, which reduces welfare all over the world.

In the last part of the paper, we study the impact of tariffs on innovation inputs. This scenario captures the notion that discriminating between imports of high-tech and innovation goods may be

[3] This channel is consistent with the empirical evidence provided by Bustos (2011) and Aghion et al. (2024), showing that higher access to foreign markets induces firms to increase their investments in innovation and technology adoption. Import tariffs work in reverse, since they reduce the market size for firms in the rest of the world, and so their return from investing in innovation.

[4] See Halpern et al. (2015) and Gopinath and Neiman (2014) for empirical evidence supporting this effect.

hard, since many goods fulfill both roles.[5] Moreover, this seems relevant to understand the impact of some policies recently introduced in the US, such as the fees imposed on foreign high-skilled workers to obtain visas. More precisely, we consider a scenario in which a country imposes tariffs on imports of both high-tech and innovation goods. These blanket tariffs may have severe negative effects on the country imposing them, especially if it starts from a position of technological leadership. Restricting imports of innovation inputs, in fact, causes a progressive loss of technological rents and national income. The result is a sharp drop in welfare.

Taking stock, our analysis indicates that tariffs can have an impact on the geographical allocation of innovation activities, and may shift the balance of technological hegemony. At the same time, our work suggests that imposing import tariffs to boost domestic high-tech sectors is a risky strategy, which can easily backfire. Other policy instruments, such as subsidies to private R&D or public R&D programs, are better suited to promote innovation and technological development.

This paper is related mainly to two literatures. The first one studies innovation and trade in the global economy. Some examples of this literature are Rivera-Batiz and Romer (1991), Grossman and Helpman (1991), Atkeson and Burstein (2010), Eaton and Kortum (2002), Santacreu (2015), Benigno et al. (2025) and Cesa Bianchi et al. (2026).[6] We contribute to this literature by showing that the combination of geographically-localized knowledge spillovers and international trade in innovation inputs create incentives for countries to compete to attract technological rents and gain a position of technological hegemony.

The paper is also connected to the vast literature on tariffs and other trade policies.[7] Our model abstracts from the classic motives for imposing import tariffs, such as terms of trade manipulation, production efficiency and home market effects (Helpman and Krugman, 1989; Ossa, 2011). We highlight a different motive for tariffs, namely knowledge spillovers generated by innovation activities. In this respect, our paper builds on the literature on trade policy in presence of external returns to scale (Krugman, 1987; Young, 1991; Bartelme et al., 2025; Cuñat and Zymek, 2025). Different from this literature, we focus on external returns that originate from investment in innovation by high-tech firms.

To the best of our knowledge, the only other papers deriving the optimal trade policy in endogenous growth models are Akcigit et al. (2025), Bai et al. (2025) and Santacreu (2025). Different from them, we study an economy in which innovation requires the use of specialized inputs, which are both in limited supply in the global economy and internationally mobile. This feature creates a new rationale for imposing import tariffs on high-tech goods, based on the idea that tariffs may foster domestic investment in innovation, by reducing the demand for innovation inputs by firms

[5] One case in point is computers, which are both high-tech goods, but also inputs in the innovation process. Interestingly, computer parts and accessories have so far been exempted from the US import tariffs. As argued by Politano (2025), placing tariffs on computers imports would severely undermine the undergoing investment boom in AI technologies by US high-tech firms.

[6] See Melitz and Redding (2023) for a survey of this literature.

[7] The recent events have sparked a revival of this literature. A non-exhaustive list of recent contributions is Ambrosino et al. (2024), Auclert et al. (2025), Auray et al. (2025), Baqaee and Malmberg (2025), Bergin and Corsetti (2025) Bianchi and Coulibaly (2025), Costinot and Werning (2025), Itskhoki and Mukhin (2025), Monacelli (2025), Moro and Nispi Landi (2024) and Werning et al. (2025).

in the rest of the world.

The rest of the paper is composed of seven sections. Section 2 introduces the theoretical framework. Section 3 shows t the technological hegemon, i.e. the net importer of innovation goods, enjoys higher welfare. Section 4 studies the macroeconomic impact of import tariffs on high-tech goods. Section 5 focuses on retaliation and trade wars. Section 6 considers the effect of tariffs on imports of innovation goods. Section 7 concludes. The Appendix contains several extensions to our baseline model.

2 Model

Consider an infinite-horizon world economy composed of two countries: home h and foreign f. Time is discrete and indexed by $t \in \{0, 1, 2, ...\}$, and there is perfect foresight.

2.1 Households

Each country is inhabited by a measure one of identical households, deriving utility from the consumption of a final good, freely traded across the two countries. The lifetime utility of the representative household in country i is

$$\sum_{t=0}^{\infty} \beta^t C_{i,t}, \tag{1}$$

where $C_{i,t}$ denotes consumption and $0 < \beta < 1$ is the subjective discount factor. Each household supplies inelastically one unit of labor on the market.

Taking the consumption good as the numeraire, the households' budget constraint is

$$C_{i,t} + \frac{B_{i,t+1}}{R_t} = W_{i,t} + B_{i,t} + \Pi_{i,t}. \tag{2}$$

The left-hand side of this expression represents the household's expenditure. Hence, $C_{i,t}$ is the total expenditure in consumption, while $B_{i,t+1}$ denotes the purchase of bonds made by the household at time t. R_t is the interest rate on bonds, which is common across the two countries due to free capital mobility.

The right-hand side captures the household's income. $W_{i,t}$ denotes the wage, and hence the household's labor income. Labor is internationally immobile and so wages are country-specific. $B_{i,t}$ represents the return on investment in bonds made at time $t - 1$. Finally, $\Pi_{i,t}$ captures other sources of income, for instance dividends from firms' ownership, on which we will elaborate shortly.

At each time t, households allocate their total income between consumption expenditure and bonds purchases. Optimal saving behavior implies $R_t = 1/\beta \equiv R$.[8] The optimal consumption path also satisfies a standard transversality condition.

[8] We focus on equilibria in which households have positive consumption in all periods.

2.2 Final good production

The final good is produced by competitive firms using labor $L_{i,t}$ and a continuum of intermediate inputs indexed by $j \in [0, 2]$. We think of these intermediate inputs as goods and services produced by high-tech sectors, with large scope for productivity improvements and potential to generate knowledge spillovers. In what follows, therefore, we will refer to them as high-tech goods.

Denoting by $Y_{i,t}$ the output of the final good, the production function is

$$Y_{i,t} = (ZL_{i,t})^{1-\alpha} \int_0^2 \left(A_t^j\right)^{1-\alpha} \left(x_{i,t}^j\right)^{\alpha} dj, \tag{3}$$

where $Z \equiv \left(\alpha^{2\alpha/(1-\alpha)}(1-\alpha^2)\right)^{-1}$ is a normalizing constant, $0 < \alpha < 1$ determines the share of high-tech goods in gross output, $x_{i,t}^j$ denotes the quantity of input j used in country i, and A_t^j is the productivity, or quality, of input j.[9]

Profit maximization implies the demand functions

$$(1-\alpha)Z^{1-\alpha}L_{i,t}^{-\alpha} \int_0^2 \left(A_t^j\right)^{1-\alpha} \left(x_{i,t}^j\right)^{\alpha} dj = W_{i,t} \tag{4}$$

$$\alpha\,(ZL_{i,t})^{1-\alpha} \left(A_t^j\right)^{1-\alpha} \left(x_{i,t}^j\right)^{\alpha-1} = p_{i,t}^j, \tag{5}$$

where $p_{i,t}^j$ is the price of the high-tech input j in country i. Due to perfect competition, firms in the final good sector do not make any profit in equilibrium.

2.3 High-tech goods production and profits

Every high-tech good is produced by a single monopolist. Goods $j \in [0, 1]$ are produced by firms located in the home country, while goods $j \in [1, 2]$ are produced by firms in the foreign country. High-tech goods producers are fully owned by domestic households.

We are interested in studying the macroeconomic impact of tariffs on high-tech goods. For most of the paper, we consider scenarios in which governments set constant ad-valorem tariffs $0 \leq \tau_i \leq 1$ on imports of high-tech goods.[10] The revenue from tariffs is rebated to domestic households through lump-sum transfers.

One unit of final output is needed to manufacture one unit of high-tech good, regardless of quality. To maximize profits, each monopolist sets the price of its good according to $p_{i,t}^j = 1/\alpha$ if the good is sold domestically, and $p_{i,t}^j = 1/(\alpha(1-\tau_{-i}))$ if the good is exported. In words, each monopolist charges a constant markup $1/\alpha$ over its marginal cost. Tariffs effectively act as an increase in marginal costs for exported goods.

To simplify notation, it is convenient to define $\xi_i \equiv (1-\tau_i)^{\frac{1}{1-\alpha}}$. The variable ξ_i can be thought as a trade liberalization index. For instance, when $\xi_i = 1$ country i is fully open to imports of

[9] More precisely, for every good j, A_t^j represents the highest quality available. In principle, firms could produce using a lower quality of good j. However, the structure of the economy is such that in equilibrium only the highest quality version of each good is used in production.

[10] Hence, for each unit exported from country i to country $-i$ the producer of high-tech good j earns $(1-\tau_{-i})p_{i,t}^j$.

foreign goods, while $\xi_i = 0$ corresponds to a complete ban on imports of high-tech inputs. Using this notation, the quantity sold of a generic high-tech good j in country i is

$$x_{i,t}^j = \begin{cases} \alpha^{\frac{2}{1-\alpha}} Z A_t^j L_{i,t} & \text{if good } j \text{ is produced domestically} \\ \xi_i \alpha^{\frac{2}{1-\alpha}} Z A_t^j L_{i,t} & \text{if good } j \text{ is imported.} \end{cases} \tag{6}$$

Naturally, higher tariffs depress the quantity of intermediate inputs imported. Combining equations (3) and (6) gives

$$Y_{i,t} = \alpha^{\frac{2\alpha}{1-\alpha}} Z \left(A_{i,t} + \xi_i^\alpha A_{-i,t} \right) L_{i,t}, \tag{7}$$

where $A_{i,t}$ denotes the average productivity of high-tech goods produced by country i.[11] Hence, production of the final good is increasing in the average productivity of high-tech intermediate goods, adjusted for the tariff in the case of imported high-tech goods. Moreover, output is increasing in the exogenous component of labor productivity, and in the amount of labor employed in production. From now on, to streamline notation, we will impose the labor market clearing condition $L_{i,t} = 1$.

The profits earned by the monopolist producing good j in country i are given by

$$\varpi A_t^j \left(1 + \xi_{-i}\right),$$

where $\varpi \equiv \alpha/(1+\alpha)$. Therefore, higher quality inputs are associated with higher profits. This is the reason why firms will want to invest to increase their productivity. Barriers to trade reduce the profits of high-tech firms. In particular, when a country increases its tariff it reduces the profits earned by high-tech firms located in the rest of the world.

2.4 Investment and productivity growth

Firms operating in the high-tech sector invest in innovation to improve the quality of their products. Investment in innovation requires the use of an *innovation good*. This good captures a host of inputs that are specific to the innovation process, and that are in limited supply in the global economy. Researchers and venture capital are two examples of the innovations goods that we have in mind. Every household has a constant endowment $\bar{I}$ of the innovation good, and can sell its services both to domestic and foreign firms at price P_t^I. Hence, just like researchers and venture capital, the innovation good is internationally mobile.

A firm that invests I_t^j units of the innovation good sees its productivity evolve according to

$$A_{t+1}^j = \rho A_t^j + A_t^* I_t^j, \tag{8}$$

where A_t^* is an exogenous variable determining the productivity of investment in innovation. One could think of A_t^* as the stock of basic scientific knowledge, on which firms draw when innovating.

[11] More precisely, $A_{h,t} = \int_0^1 A_t^j dj$ and $A_{f,t} = \int_1^2 A_t^j dj$.

We will refer to A_t^* as the world technological frontier, and assume that it grows at the constant rate $1 < g < 1/\beta$.[12] We also assume that the quality of each intermediate input depreciates at rate $0 \leq 1 - \rho \leq 1$.

Innovation-based endogenous growth models typically posit that knowledge is only partly excludable. For instance, this happens if inventors cannot prevent others from drawing on their ideas to innovate. For this reason, in most endogenous growth frameworks, the social return from investing in innovation is higher than the private one.[13] We introduce this effect by assuming that at the start of every period there is a constant probability $1 - \eta$ that the incumbent firm dies, and is replaced by another firm that inherits its technology. Moreover, following a long-standing literature arguing that geographical proximity fosters knowledge spillovers (Audretsch and Feldman, 1996; Moretti, 2021), we assume that the technology of a dying firm is inherited by a new firm located in the same country.

Firms producing high-tech goods choose investment in innovation to maximize their discounted stream of profits net of investment costs. Hence, a generic firm j in country i sets investment to maximize

$$\sum_{t=0}^{+\infty} \left(\frac{\eta}{R}\right)^t \left(\varpi A_t^j \left(1 + \xi_{-i}\right) - P_t^I I_t^j\right), \tag{9}$$

subject to (8) and the non-negativity constraint on investment $I_t^j \geq 0$. Firms discount profits using the interest rate R, adjusted for the survival probability η.

Optimal investment in innovation for firms in country i is such that[14]

$$\frac{P_t^I}{A_t^*} \geq \sum_{\zeta=1}^{+\infty} \frac{\eta^\zeta \rho^{\zeta-1}}{R^\zeta} \varpi \left(1 + \xi_{-i}\right), \qquad I_t^j \geq 0, \tag{10}$$

with one expression holding as a strict equality. Intuitively, firms equalize the marginal cost from performing research P_t^I/A_t^*, to its marginal benefit. The marginal benefit is given by the marginal increase in the whole stream of discounted profits, adjusted for the firm survival probability and for the depreciation of the quality of the input. If the marginal cost of investment exceeds the marginal benefit, then firms set investment equal to zero.

The innovation process thus captures two elements that are the foundations of our theory. First, innovation activities by high-tech sectors - here captured by investment by producers of intermediate inputs - generate geographically localized knowledge spillovers. Second, innovation activities require specialized inputs, such as researchers, venture capital, specialized equipments, and so on, that are both internationally mobile, and in limited supply in the global economy.

We model these two features starkly, to highlight clearly the economic mechanisms that we are interested in. In Appendix B, we enrich the model by adding transport costs and a partly elastic supply of innovation goods, and show that these two extensions do not change the gist of

[12] The condition $g < 1/\beta$ is needed to ensure that households' utility is finite.

[13] See for instance Romer (1990) and Aghion and Howitt (1992).

[14] We derive this result in Appendix A.

our results.

2.5 Aggregation and market clearing

Using equations (4) and (6), we can write households' labor income in country i as

$$W_{i,t} = (1-\varpi)\left(A_{i,t} + \xi_i^{\alpha} A_{-i,t}\right). \tag{11}$$

Labor income is proportional to labor productivity. Labor productivity depends on $A_{i,t}$ and $A_{-i,t}$ because firms produce the final good by combining labor with domestic and imported high-tech inputs. Moreover, import tariffs depress domestic labor productivity by reducing the use of foreign intermediate inputs. This effect explains why labor income is increasing in the trade openness index ξ_i.

Households also derive income from the dividends distributed by the firms, that is operating profits net of investment costs, from the ownership of the innovation good, and from the lump-sum transfers received by the domestic government. It follows that

$$\Pi_{i,t} = \underbrace{\varpi\left(1+\xi_{-i}\right)A_{i,t} - P_t^I I_{i,t}}_{\text{high-tech dividends}} + \underbrace{P_t^I \bar{I}}_{\text{sales of inn. good}} + \underbrace{\varpi \frac{(1-\xi_i^{1-\alpha})\xi_i^{\alpha}}{1-\alpha} A_{-i,t}}_{\text{fiscal revenue}}, \tag{12}$$

where $I_{i,t}$ denotes aggregate investment by firms in country i.[15] The gross domestic product is then given by

$$GDP_{i,t} = \underbrace{(1-\varpi)\left(A_{i,t} + \frac{\xi_i^{\alpha} - \alpha\xi_i}{1-\alpha} A_{-i,t}\right)}_{\text{labor income}} + \underbrace{\varpi\left(1+\xi_{-i}\right)A_{i,t}}_{\text{high-tech profits}} + \underbrace{P_t^I \bar{I}}_{\text{sales of inn. good}}. \tag{13}$$

This expression shows how, holding technology constant, tariffs affect GDP. First, import tariffs depress GDP by decreasing the use of foreign high-tech goods, and so labor income.[16] Second, tariffs imposed by the rest of the world reduce GDP by lowering the profits earned abroad by domestic high-tech firms.

Turning to the expenditure side of the economy, GDP is equal to the sum of consumption, investment and net exports, and so

$$GDP_{i,t} = C_{i,t} + P_t^I I_{i,t} + \frac{B_{i,t+1}}{R_t} - B_{i,t}. \tag{14}$$

[15] Hence, $I_{h,t} \equiv \int_0^1 I_t^j dj$ and $I_{f,t} \equiv \int_1^2 I_t^j dj$.

[16] More precisely, a rise in import tariffs triggers two effects. First, as shown by equation (11), it reduces labor productivity and labor income. Second, it leads to an increase in fiscal revenue, and so in the transfer that households receive from the government. This second effect, however, is always dominated by the first one. To streamline the exposition, we therefore lump these two effects together in a single labor income effect.

Finally, global markets have to clear

$$\sum_{i=h,f} C_{i,t} = \sum_{i=h,f} A_{i,t}\left(1 + (1-\varpi)\frac{\xi_{-i}^{\alpha} - \alpha\xi_{-i}}{1-\alpha} + \varpi\xi_{-i}\right) \tag{15}$$

$$I_{h,t} + I_{f,t} = 2\bar{I}. \tag{16}$$

The first expression implies that, at the global level, consumption is equal to production of the final good, net of the amount used to produce high-tech inputs. The second expression ensures that investment is equal to the global supply of the innovation good.

2.6 Equilibrium

To describe the equilibrium, it is useful to express some variables in terms of their ratio with respect to the world technological frontier A_t^*. So, for a generic variable X_t, we will define $x_t \equiv X_t/A_t^*$.

Using this definition, equation (8) becomes

$$I_{i,t} = g a_{i,t+1} - \rho a_{i,t}, \tag{17}$$

where $a_{i,t}$ can be thought as country i's proximity to the technological frontier. This equation implies that higher investment in innovation brings a country closer to the world technological frontier.

Using expression (10), firms' optimal investment behavior can be written as

$$p_t^I \geq \frac{\eta\varpi}{R-\eta\rho}\left(1+\xi_{-i}\right), \qquad g a_{i,t+1} \geq \rho a_{i,t}, \tag{18}$$

with one expression holding as a strict equality. Hence, a country that does not innovate, which happens when the first inequality holds strictly, sees its proximity to the frontier decrease at rate g/ρ.

Equations (13) and (14) become

$$gdp_{i,t} = (1-\varpi)\left(a_{i,t} + \frac{\xi_i^{\alpha} - \alpha\xi_i}{1-\alpha}a_{-i,t}\right) + \varpi(1+\xi_{-i})a_{i,t} + p_t^I\bar{I} \tag{19}$$

$$gdp_{i,t} = c_{i,t} + p_t^I\left(g a_{i,t+1} - \rho a_{i,t}\right) + b_{i,t+1}\frac{g}{R} - b_{i,t}. \tag{20}$$

The global market clearing conditions for consumption and investment are

$$\sum_{i=h,f} c_{i,t} = \sum_{i=h,f} a_{i,t}\left(1 + (1-\varpi)\frac{\xi_{-i}^{\alpha} - \alpha\xi_{-i}}{1-\alpha} + \varpi\xi_{-i}\right) \tag{21}$$

$$2\bar{I} = g\left(a_{h,t+1} + a_{f,t+1}\right) - \rho\left(a_{h,t} + a_{f,t}\right). \tag{22}$$

We are ready to define a competitive equilibrium as a path for $\{a_{i,t+1}, gdp_{i,t}, c_{i,t}, b_{i,t+1}\}_{i,t}$ and $\{p_t^I\}_t$ satisfying expressions (18)-(22), given the initial conditions $\{a_{i,0}, b_{i,0}\}_i$ and trade policies

$\{\xi_i\}_i$.

3 The exorbitant technological privilege

We now introduce two notions that are at the heart of our analysis: technological hegemony and the exorbitant technological privilege. First, we define the technological hegemon as the country that gets closer to the technological frontier by attracting foreign innovation goods. We then show that the technological hegemon enjoys an exorbitant technological privilege, originating from the fact that the owners of the innovation good appropriate only the private return to innovation, which lies below the social one.

To pin down these two notions, let us focus on a world under free trade ($\xi_h = \xi_f = 1$), and start by considering the steady state of the model, in which all the variables are constant. Using the market clearing condition for the innovation good gives

$$a_h + a_f = \frac{2\bar{I}}{g - \rho}, \tag{23}$$

where the absence of a time subscript denotes the steady state value of a variable. Therefore, the global endowment of innovation goods pins down the average distance from the frontier of the two countries.

How is technological leadership determined under free trade? Since all the firms have the same incentives to invest in innovation, the first expression in (18) holds with equality in both countries. This implies that both countries have positive investment, and their distance from the frontier is equal to

$$a_i = \frac{I_i}{g - \rho}.$$

Any combination of $a_h > 0$ and $a_f > 0$ satisfying (23) is consistent with a steady state equilibrium. In fact, under free trade, our model does not pin down which country is the technological hegemon.[17] In any case, the technological hegemon is the net importer of innovation goods (i.e. if $a_i > a_{-i}$ then $I_i > \bar{I}$).

The equilibrium price of the innovation good is pinned down by the private return to innovation

$$p^I = \frac{2\eta\varpi}{R - \eta\rho}. \tag{24}$$

Notice that higher knowledge spillovers, i.e. a lower η, are associated with a lower private return from investing in innovation, pushing down global demand for the innovation good and its price.

[17] To be clear, we do not see this degree of indeterminacy as a deep feature of our model. With an infinitesimal cost of exporting the innovation good, the only equilibrium under free trade would be symmetric, that is such that $a_h = a_f$. We explore this extension in Appendix B, and show that all of our main insights apply also to this case.

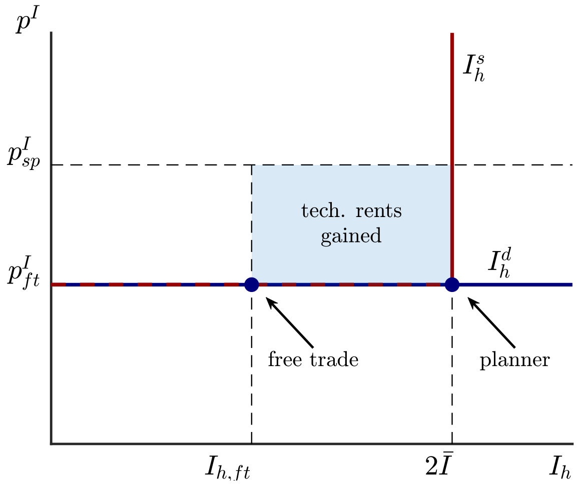

Figure 1: Equilibrium on the market for innovation goods.

Now focus on GDP in country i, net of investment in innovation. This is given by

$$gdp_i - p^I I_i = 2\left(\underbrace{(1-\varpi)\frac{\bar{I}}{g-\rho}}_{\text{labor income}} + \underbrace{\varpi\frac{\eta\bar{I}}{R-\rho\eta}}_{\text{sales of innovation good}} + \underbrace{a_i\varpi\left(1-\frac{\eta(g-\rho)}{R-\rho\eta}\right)}_{\text{technological rents}}\right). \tag{25}$$

The first two terms capture respectively labor income, and the revenue from selling the innovation good. These two sources of income are identical across the two countries, because both intermediate inputs and the innovation good are freely traded internationally.

The last term captures the technological rents earned by country i, i.e. the difference between high-tech profits and expenditure on innovation. Expression (25) shows that the technological hegemon enjoys higher technological rents, i.e. an exorbitant technological privilege. These rents arise because the social return to innovation is higher than the private return, which pins down the price of the innovation good. This explains why the exorbitant technological privilege is particularly large when knowledge spillovers are strong (i.e. when η is low).

We conclude this section by noting that, from a national perspective, imports of innovation goods by private firms are inefficiently low. To see this point, imagine that investment in innovation in the home country was carried out by a social planner seeking to maximize domestic welfare. Internalizing the full social return from innovation, the home planner would purchase all the global endowment of innovation goods. This happens because the price of innovation goods is too low from a social perspective, as it is pinned down by the private return to innovation. Through this strategy, the home country would maximize its technological rents, leading to welfare gains for its citizens. This is, however, a zero-sum game. In fact, households in the foreign country experience a welfare loss exactly equivalent to the welfare gains enjoyed by the home country.

Figure 1 shows these results graphically. The I_h^d schedule represents the demand for innovation goods by high-tech firms located in the home country. This is just a horizontal line at $p^I_{ft} \equiv \frac{2\eta\varpi}{R-\eta\rho}$, which is the price that equates the marginal cost of innovating to its private marginal benefit. The

I_h^s schedule represents the supply of innovation goods available to home firms, which is equal to $2\bar{I} - I_f^d$, where I_f^d denotes the demand for the innovation good by foreign high-tech firms. This schedule also has a horizontal portion at p_{ft}^I, and it becomes vertical at $I_h^s = 2\bar{I}$ for values of p^I exceeding p_{ft}^I, since for those prices foreign firms do not invest in innovation.[18]

Under free trade, the equilibrium price of the innovation good equals $p^I = p_{ft}^I$ and any value of $I_h \in [0, 2\bar{I}]$ is a possible equilibrium. As an example, the diagram shows a case in which investment by home firms is equal to $I_{h,ft}$. The diagram also shows how the allocation changes if investment in innovation in the home country is set by a national planner. The home planner would purchase all the innovation goods ($I_h = 2\bar{I}$) at the price prevailing in the free-trade equilibrium, which is the lowest price that sellers of the innovation good are willing to accept. Now define $p_{sp}^I \equiv \frac{2\varpi}{R-\rho}$ as the shadow value that the planner attaches to a unit of investment good, reflecting the social return to innovation. The increase in technological rents earned by the home country would then be equal to $(p_{sp}^I - p_{ft}^I)(2\bar{I} - I_{h,ft})$, corresponding to the shaded area in the diagram. These are exactly equal to the technological rents lost by the foreign country.[19]

4 Tariffs and technological hegemony

Having established that countries have an incentive to compete to attract the scarce global supply of innovation goods, we now show that this may be done with a particular form of import tariffs. The key idea is simple. Suppose that a country imposes a tariff on imports of foreign high-tech goods. As a result, high-tech firms in the rest of the world will suffer a drop in market size and profits. Investment in innovation by foreign firms will decline, and innovation goods - as well as the associated technological rents - will flow towards the country that imposed the tariff. Import tariffs can thus be used to gain a position of technological hegemony. In what follows, we use our

[18] More precisely, the I_h^d schedule is given by

$$I_h = \begin{cases} 0 & \text{if } p^I > p_{ft}^I \\ [0, +\infty] & \text{if } p^I = p_{ft}^I, \end{cases}$$

while the I_h^s schedule is given by

$$I_h = 2\bar{I} - I_f^d = \begin{cases} [0, 2\bar{I}] & \text{if } p^I = p_{ft}^I \\ 2\bar{I} & \text{if } p^I > p_{ft}^I, \end{cases}$$

where $p_{ft}^I \equiv \frac{2\eta\varpi}{R-\eta\rho}$.

[19] In a bit more detail, we define technological rents as the dividends distributed by high-tech firms, that is the difference between their profits and expenditure on innovation goods. In the initial free-trade steady state, the technological rents earned by the home country are thus

$$2\varpi a_{h,ft} - p_{ft}^I I_{h,ft} = \left(\frac{2\varpi}{g-\rho} - \frac{2\eta\varpi}{R-\eta\rho} \right) I_{h,ft},$$

where we have used $I_{h,ft} = a_{h,ft}(g-\rho)$ and $p_{ft}^I = \frac{2\eta\varpi}{R-\eta\rho}$. Now imagine that a social planner buys all the innovation goods from the foreign country at the price p_{ft}^I. With a bit of algebra, one can show that the present value of technological rents earned by the home country increases by

$$\frac{R}{R-g}(2\bar{I} - I_{h,ft}) \frac{R(1-\eta)}{(R-\rho)(R-\rho\eta)} = \frac{R}{R-g}(2\bar{I} - I_{h,ft})(p_{sp}^I - p_{ft}^I),$$

and hence the present value gains in technological rents equals (a scaled version of) the shaded area in Figure 1.

model to explore the strengths and limitations of this strategy.[20]

4.1 Tariffs on high-tech goods

We begin by considering a scenario in which one country unilaterally imposes tariffs on imports of high-tech goods. More precisely, assume that the economy starts from a free-trade steady state, in which $a_{h,0} + a_{f,0} = 2\bar{I}/(g-\rho)$. From period $t = 0$ on, the home government imposes tariffs on high-tech imports ($\xi_h < 1$), while the foreign country maintains free trade ($\xi_f = 1$). This shock is fully unanticipated before period 0, but from then on agents have perfect foresight.

Let us start by tracing the impact of import tariffs on innovation. Having lost access to the home market, foreign high-tech firms experience a drop in the return to investment, and so innovation goods flow towards the home country.[21] In our simple model, this effect is so strong that foreign firms stop innovating altogether, and home firms absorb all the innovation goods ($I_{f,t} = 0$, $I_{h,t} = 2\bar{I}$), while the price of the innovation good remains equal to its value in the free-trade steady state.[22] Figure 2 captures graphically these results. The tariff reduces the demand for innovation goods by foreign firms, causing a downward shift of the I_h^s schedule.[23] As a result, home firms purchase the whole global endowment of innovation goods, at a price equal to the one in the initial free-trade steady state.

In the long run, home productivity converges to $a_h = 2\bar{I}/(g-\rho)$, while a_f converges to zero. During the transition, in both countries $a_{i,t}$ approaches its long-run value at rate $1 - \rho/g$, that is

$$a_{h,t} = \left(\frac{\rho}{g}\right)^t a_{h,0} + \left(1 - \left(\frac{\rho}{g}\right)^t\right) \frac{2\bar{I}}{g-\rho}$$

$$a_{f,t} = \left(\frac{\rho}{g}\right)^t a_{f,0}.$$

Hence, the quality of home high-tech goods grows over time, while foreign high-tech goods get further and further away from the technological frontier.

The GDP response depends on the horizon at which one looks at. In the home country, GDP

[20] To be clear, our focus on tariffs is motivated by the prominence that they have gained in the current policy debate. In fact, there are likely to be better policy tools that governments can use to attract technological rents. We plan to explore them in future research.

[21] The empirical evidence provided by Bustos (2011) and Aghion et al. (2024) is consistent with this effect.

[22] To see this result, suppose that investment in innovation by foreign firms was positive. Then the optimal investment condition (18) would imply

$$p_t^I = \frac{\eta\varpi}{R - \eta\rho}(1 + \xi_h) \geq \frac{\eta\varpi}{R - \eta\rho} 2,$$

which clearly cannot hold. In Appendix B, we consider a version of the model in which this reallocation effect is weakened by transport costs.

[23] With the tariff, the I_h^s schedule becomes

$$I_h^s = 2\bar{I} - I_f^d = \begin{cases} [0, 2\bar{I}] & \text{if } p^I = \frac{(1+\xi_h)\eta\varpi}{R-\eta\rho} = \frac{1+\xi_h}{2} p_{ft}^I \\ 2\bar{I} & \text{if } p^I > \frac{1+\xi_h}{2} p_{ft}^I. \end{cases}$$

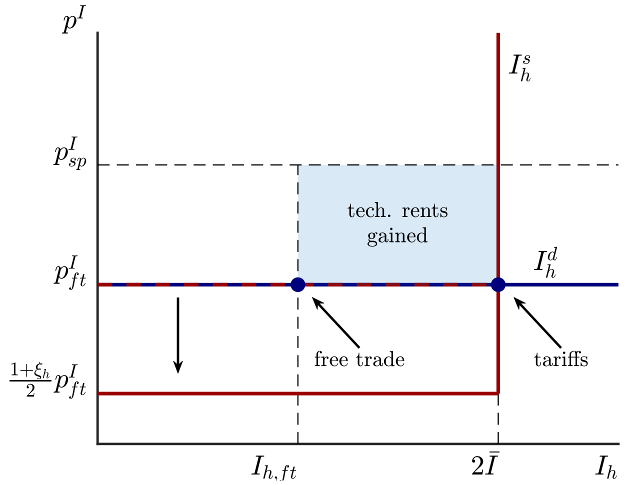

Figure 2: Equilibrium on the market for innovation goods with tariffs.

evolves according to

$$\Delta^{ft} gdp_{h,t} = \left(\underbrace{-(1-\varpi)\left(1 - \frac{\xi_h^\alpha - \alpha\xi_h}{1-\alpha}\right)\left(\frac{\rho}{g}\right)^t}_{\text{labor income}} + \underbrace{2\varpi\left(1 - \left(\frac{\rho}{g}\right)^t\right)}_{\text{high-tech profits}} \right) a_{f,0}, \tag{26}$$

where we use $\Delta^{ft} x_t \equiv x_t - x^{ft}$ to denote the deviation of a variable x_t from the free trade steady state. The first term on the right-hand side captures the decline in labor productivity and labor income driven by the reduced access to foreign intermediate inputs.[24] This effect is particularly salient at short horizons. In fact, on impact ($t = 0$), this is the only effect at play. In the long run ($t \to +\infty$), instead, this effect vanishes. The reason is that as $a_{h,t}$ increases labor productivity in the home country rises, until it fully recovers its initial value.[25] The second term on the right-hand side encapsulates the rise in profits earned by high-tech firms. This effect gets stronger over time, as domestic high-tech firms improve the quality of their products through higher investment in innovation. Indeed, this is the only effect operating in the long run.

Taken together, these two effects imply that import tariffs generate an initial drop in GDP in the home economy, followed by a rise in the long run. Moreover, expression (26) implies that the strength of the movements in GDP is proportional to the productivity of foreign high-tech goods in the initial free-trade steady state ($a_{f,0}$). On the one hand, in fact, the impact on GDP of the loss of access to foreign intermediate inputs is higher the more productive these inputs are. On the other hand, a higher value of $a_{f,0}$ is associated with larger profits to be appropriated by home high-tech firms upon the imposition of import tariffs.

In the foreign country, instead, GDP unambiguously drops, driven by the lower profits earned

[24] Halpern et al. (2015) and Gopinath and Neiman (2014) show empirically the connection between imported intermediate inputs and domestic productivity.

[25] This is due to the assumption of constant returns to investment in innovation. As we discuss in Appendix B, with an elastic supply of innovation goods, trade restrictions could cause permanent drops in labor productivity.

by its high-tech firms. More precisely, GDP in the foreign country evolves according to

$$\Delta^{ft} gdp_{f,t} = -\varpi \left(2 - (1 + \xi_h) \left(\frac{\rho}{g} \right)^t \right) a_{f,0}. \tag{27}$$

The GDP losses experienced by the foreign country thus increase over time. This happens because high-tech firms stop investing in innovation, leading to a gradual loss of the high-tech profits earned by the foreign country. This result suggests that the full damage caused by trade barriers imposed by the rest of the world may take time to materialize.

Turning to world output, tariffs cause a temporary recession. More precisely, global GDP evolves according to

$$\Delta^{ft}(gdp_{h,t} + gdp_{f,t}) = -\left((1-\varpi) \left(1 - \frac{\xi_h^\alpha - \alpha \xi_h}{1-\alpha} \right) + \varpi (1 - \xi_h) \right) \left(\frac{\rho}{g} \right)^t a_{f,0}.$$

Global GDP drops in the short run, because restricting access to foreign inputs reduces productivity in the home economy. This loss is, however, temporary. In the long run higher investment in innovation by home firms fully compensates for the loss of high-tech foreign goods. While it would be easy to imagine scenarios in which tariffs cause long-run output losses, the key insight here is that the impact of trade barriers on global GDP is likely to be greater in the short run. As time goes by, the reason is, the shifting pattern of innovation mitigates the negative effect of trade restrictions on world output.

What about the impact of tariffs on welfare? Since households' utility is linear in consumption, to answer this question one has to evaluate how tariffs affect the present value of income net of investment. In the home country, the impact of tariffs on welfare is given by

$$\sum_{t=0}^{+\infty} \left(\frac{g}{R} \right)^t \Delta^{ft}(gdp_{h,t} - p^I I_{h,t})$$
$$= \frac{R}{R-\rho} \left(\underbrace{2\varpi \left(\frac{R - \eta g}{R - \eta \rho} \frac{R-\rho}{R-g} - 1 \right)}_{\text{technological rents}} - \underbrace{(1-\varpi) \left(1 - \frac{\xi_h^\alpha - \alpha \xi_h}{1-\alpha} \right)}_{\text{labor income}} \right) a_{f,0}. \tag{28}$$

This expression shows that the impact of import tariffs on welfare is in principle ambiguous, and determined by two contrasting effects. On the one hand, import tariffs increase welfare because they lead to higher technological rents. On the other hand, import tariffs depress welfare because of the efficiency losses caused by restricting imports of foreign high tech goods.

The positive effect is more likely to dominate when local knowledge spillovers are strong, i.e. when η is low. In fact, equation (28) indicates that placing a tariff on imports of high-tech goods will surely decrease welfare if investment in innovation does not generate positive externalities, i.e. if $\eta = 1$. The reason is that our model abstracts from all the classic rationales for import tariffs typically present in economies with monopolistically competitive firms, as described in chapter 7 of

Helpman and Krugman (1989). Terms of trade effects are absent because the ex-factory prices of high-tech goods are all equal to $1/\alpha$, and so they do not depend on import tariffs. The production efficiency effect does not operate, because by expression (6) the demand for domestic high-tech goods is not affected by import tariffs. Finally, the home market effect is shut off because there are no transport costs for intermediate goods.

Moreover, equation (28) shows that small tariffs are more likely to improve welfare (assuming that the rest of the world maintains free trade).[26] The combination of free mobility of the innovation good and constant returns to innovation, in fact, makes investment in innovation extremely sensitive to the tariff rate. Hence, an infinitesimally small tariff attracts all the technological rents, while minimizing the efficiency losses due to lower access to foreign high-tech goods.[27] One could then conclude that a very small tariff on imports of high-tech goods may deliver high welfare gains. We will put this notion into question in Section 5, where we will discuss optimal tariffs with retaliation.

Turning to the foreign country, the effect of tariffs on welfare is given by

$$\sum_{t=0}^{+\infty}\left(\frac{g}{R}\right)^t \Delta^{ft}(gdp_{f,t}-p^I I_{f,t}) = -\frac{R}{R-\rho}\varpi\left(2\frac{R-\eta g}{R-\eta\rho}\frac{R-\rho}{R-g}-(1+\xi_h)\right)a_{f,0}. \tag{29}$$

Welfare in the foreign country thus unambiguously drops, driven by the loss of technological rents suffered by foreign high-tech firms. As we will see in Section 5, this effect will shape the incentives to retaliate for the foreign country.

Tariffs end up lowering also global welfare, defined as the sum of the utility of all the world's citizens. This happens because tariffs depress the present value of global output, and so the global supply of consumption goods. The conclusion is that a country can enjoy welfare gains from imposing import tariffs only by causing even larger losses in the rest of the world.

4.2 Numerical exercise

We explore further the properties of the model by performing a simple calibration exercise. To be clear, the objective of this exercise is not to provide a careful quantitative evaluation of the framework or to replicate any particular historical event. In fact, both of these tasks would require a much richer model. Rather, our aim is to show that, under a reasonable parametrization, the magnitudes implied by the model are quantitatively relevant and reasonable.

We let one period correspond to one year. We set $g = 1.025$ so that output in steady state grows by 2.5 percent per year, and $\beta = 0.9615$ so that the yearly interest rate is 4 percent. We target a profit share in GDP of 10%, which requires setting $\alpha = 1/9$. We set $\rho = 0.85$ to capture a yearly obsolescence of knowledge of 15%, in line with the depreciation of the R&D stock estimated by the Bureau of Labor Statistics.

[26] Notice that the right hand side of expression (28) is increasing in ξ_h for $\xi_h < 1$.

[27] Of course, as we show in Appendix B, this is no longer the case in presence of transport costs for the innovation good.

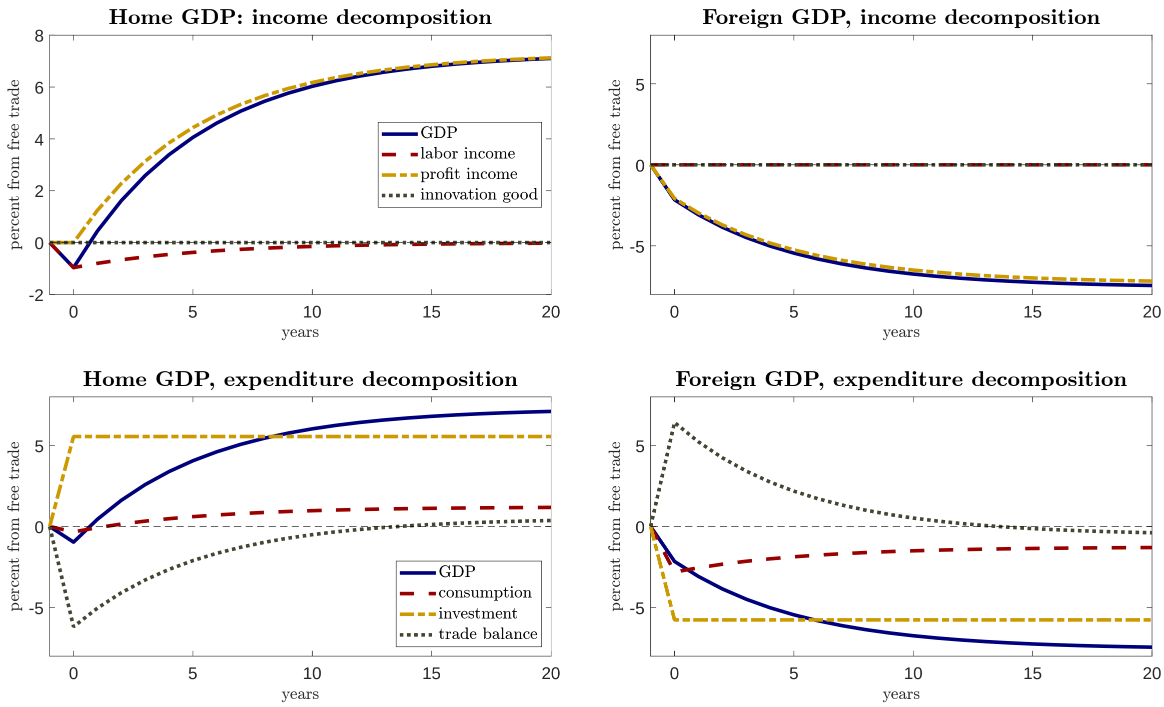

Figure 3: Impact of import tariffs on high-tech goods imposed by the home country. Notes: GDP is expressed as percent deviation from its initial free-trade steady state. The components of GDP are expressed as percent deviation from their respective steady states, weighted by their respective steady state shares in GDP. This ensures that the components sum to total GDP.

An important parameter in our model is η, which determines the strength of the knowledge spillovers caused by innovation activities. We set this parameter following the empirical estimates provided by Bloom et al. (2019) on knowledge spillovers within U.S. firms. They find that, due to knowledge externalities, the social return to R&D is two to four times larger than the private one. To be conservative, we pick η so that the social return to R&D is twice the private one in our model. This procedure yields $\eta = 0.963$.[28]

We consider a scenario in which a technologically advanced economy, such as the United States, imposes a large tariff on its imports. We thus assume that the economy starts from a free-trade steady state in which the home country is 50% more advanced technologically than the foreign country ($a_{h,0} = 0.6 * \frac{2\bar{I}}{g-\rho}$ versus $a_{f,0} = 0.4 * \frac{2\bar{I}}{g-\rho}$). In period $t = 0$ the home country engineers a previously unexpected increase in its import tariffs. More precisely, the home government sets $\tau_h = 52.7\%$, so that $\xi_h = 0.43$. As we explain in Section 5, this is the optimal tariff from the perspective of the home country, under the threat that the foreign country may retaliate.

[28]To set η, we use the fact that on the balanced growth path the private return from R&D is given by

$$r_p^I \equiv \frac{1}{\beta} - 1 = \eta \frac{2\varpi + \rho p^I}{p^I} - 1,$$

while the social return, which internalizes the inter-firms knowledge spillovers, is given by

$$r_s^I \equiv \frac{2\varpi + \rho p^I}{p^I} - 1.$$

Setting $\eta = 0.963$ implies that $r_s^I = 2r_p^I$.

Figure 3 shows the results. The left panels display the impact on home GDP, which we decompose into its income (upper panel) and expenditure components (lower panel).[29] The right panels show the impact on GDP in the foreign country, again split according to income and expenditure.

All the dynamics are in line with what we argued above. In particular, import tariffs trigger an initial drop in home GDP due to lower labor productivity, which is compensated by a long-run rise due to higher high-tech profits. In the foreign country, the progressive erosion of high-tech profits causes a gradual decline in GDP. On the expenditure side, the home country experiences an increase in investment, matched by an equivalent decline in the foreign country.

Our analytic results imply that the impact of tariffs on consumption and welfare in the home country is in principle ambiguous. It turns out that, in this numerical example, the imposition of import tariffs increases consumption in the home country. More precisely, home households experience an increase in welfare equivalent to a permanent rise by 1.19% of consumption in the initial free-trade steady state.[30] The opposite happens in the foreign country, which experiences a welfare loss equivalent to a permanent drop in consumption in the free-trade steady state by 1.47%. Hence, while the home country raises its welfare with tariffs, this comes at the expense of even larger welfare losses for the rest of the world. In fact, the global economy as a whole experiences a decline in welfare equal to a 0.13% permanent reduction of its consumption in the initial free-trade steady state.

We conclude with a remark on the impact of tariffs on the trade balance. After imposing import tariffs, the home country experiences a stream of trade deficits. These trade deficits finance the investment boom by the home high-tech sector, as well as the rise in consumption by home households. This is just a symptom of the fact that putting a tariff on imports of foreign high-tech goods causes short-run output losses, compensated by long-run output gains. This result calls into question the idea that a successful trade policy should lead to an improvement of the trade balance.[31]

5 Retaliation and trade wars

Our model suggests that a country may enjoy welfare gains by charging a tariff on imports of foreign high-tech goods. But what if the rest of the world has the option to retaliate? To address

[29] We perform the income split by using equations (26) and (27). To perform the expenditure split, we need to take a stance on the dynamics of consumption. Because of linear utility, indeed, the allocation of consumption across periods is indeterminate. However, this indeterminacy would disappear if utility from consumption featured even slightly decreasing returns, and consumption in the two countries would be proportional to each other. We use this criterion to refine the equilibrium.

[30] We compute the consumption equivalent by using the equation

$$equ_{h,0} = (w_{h,0}(1 - \beta g)/c_h^{ft} - 1) * 100,$$

where c_h^{ft} denotes home consumption in the free trade steady state, and $w_{h,0}$ denotes welfare in the home country at time 0 conditional on tariffs being imposed, given by the equation $w_{h,0} = \sum_{t=0}^{\infty} (\beta g)^t c_{h,t}$.

[31] Our model has also implications for gross capital flows. With a slight stretch of interpretation, one can interpret the sales of innovation goods to foreign firms as venture capital investments. Under this interpretation, imposing a tariff on high-tech imports produces a wave of venture capital inflows.

this question, we now consider what happens if both countries set their tariffs on high-tech imports to maximize their national welfare.

More precisely, we derive Stackelberg equilibria in which the home country moves first, that is it sets ξ_h at the start of period 0 and commits to its trade policy from then on. Having observed ξ_h, the foreign country then sets ξ_f. As usual, the equilibrium of this game is found by going backward. Therefore, we first derive the optimal retaliation strategy of the foreign country, taking as given a trade policy implemented by the home country. We then take the perspective of the home government, and derive the tariff that maximizes its citizens' welfare, given the optimal retaliation strategy played by the foreign country.

Throughout this section, we assume that both countries face an upper bound on the tariff rate that they can impose. In particular, we assume that $\tau_i \leq \bar{\tau}$, which implies that $\xi_i \geq \bar{\xi} \equiv (1-\bar{\tau})^{\frac{1}{1-\alpha}}$. This upper bound could arise from the ability of the private sector to circumvent trade restrictions, if the economic gains from doing so are sufficiently large, or from political economy considerations. The case $\bar{\xi} = 0$ corresponds to a scenario in which trade policies can be perfectly enforced.

5.1 Optimal retaliation

Imagine that the home country imposes a tariff on imports of foreign high-tech goods ($\xi_h < 1$). Will it be optimal for the foreign country to retaliate and set $\xi_f < 1$, or to maintain free trade and set $\xi_f = 1$? The answer, as we will see, is that it depends.

There are two effects that shape the optimal retaliation strategy. On the one hand, retaliating reduces access to the high-tech inputs produced by the home country. This effect is associated with a loss in labor productivity and welfare. On the other hand, retaliating may help the foreign country to retain or even boost its technological rents, which positively affects welfare. This happens if the foreign country sets $\xi_f \leq \xi_h$, so as to depress the return to innovation in the home country by at least as much as the home country has depressed the return to innovation in the foreign country. The optimal retaliation strategy strikes a balance between these two forces.

The logic above suggests that it is never optimal to retaliate by setting $\xi_f > \xi_h$. In this case, in fact, the foreign country would not gain any technological rents, while suffering the productivity losses triggered by the restricted imports of home high-tech inputs. Hence, if the foreign country retaliates, it will impose a tariff at least as large as the home country one.

To move forward, we need to take a stance on how technological rents are split when $\xi_h = \xi_f$. In this scenario, the return to innovation is equalized across the two countries and the geographical allocation of innovation activities is indeterminate. While different options are possible, we assume that if $\xi_h = \xi_f$ then technological rents are determined by history, so that $a_{i,t} = a_{i,0}$ for all $t > 0$.

Let us first assume that $\xi_h > \bar{\xi}$, so that the tariff implemented by the home country lies below the upper bound. In case of retaliation, it is then optimal for the foreign country to set a tariff just slightly above the one imposed by the home country, so that $\xi_f = \xi_h - \epsilon$ with $\epsilon \to 0$. In this way, it will gain all the technological rents, while minimizing the income losses due to reduced access to imported high-tech inputs.[32]

We are left with two possibilities. Either the foreign country does not retaliate ($\xi_f = 1$), or it retaliates by setting ξ_f slightly below ξ_h. To derive the optimal policy, the foreign country has to compare its welfare under these two scenarios. As we showed in Section 4, welfare in the foreign country in absence of retaliation is given by expression (29). Instead, if the foreign country retaliates its welfare is equal to

$$\sum_{t=0}^{+\infty}\left(\frac{g}{R}\right)^t \Delta^{nr}(gdp_{f,t} - p_t^I I_{f,t}) = \frac{R}{R-\rho}\left(\underbrace{\varpi(1+\xi_h)\left(\frac{R-\eta g}{R-\eta\rho}\frac{R-\rho}{R-g} - 1\right)(a_{h,0}+a_{f,0})}_{\text{technological rents}}\right.$$
$$\left. - \underbrace{(1-\varpi)\left(1 - \frac{\xi_f^\alpha - \alpha\xi_f}{1-\alpha}\right)a_{h,0}}_{\text{labor income}} - \underbrace{\frac{R-\rho}{R-g}(1-\xi_h)\frac{\eta\varpi\bar{I}}{R-\eta\rho}}_{\text{sales of innovation good}}\right), \quad (30)$$

where $\xi_f = \xi_h - \epsilon$ with $\epsilon \to 0$, and $\Delta^{nr}x_t \equiv x_t - x_t^{nr}$ denotes the deviation of a variable x_t from its path under the no-retaliation scenario derived in Section 4. The first term on the right-hand side captures the technological rents gained through retaliation. These are proportional to $a_{h,0} + a_{f,0}$, since under the no-retaliation scenario the foreign country would eventually lose all the profits. The second term captures the productivity loss due to lower access to imports of high-tech goods. The third term captures the loss of income from the sales of the innovation goods, since retaliation reduces p^I by a factor $1 - \xi_h$.[33]

It is optimal for the foreign country to retaliate when expression (30) is positive, otherwise no retaliation occurs. Expression (30) shows that the incentives to retaliate are decreasing in the tariff imposed by the home country. Intuitively, this is due to two effects. First, to gain technological rents the foreign country has to set $\xi_f = \xi_h - \epsilon$. This means that the welfare losses due to lower labor income upon retaliation are increasing in the tariff imposed by the home country. Second, the technological rents appropriated through retaliation are decreasing in the tariff imposed by the home country. Intuitively, gaining a leadership position in high-tech industries is less valuable if the rest of the world is imposing large tariffs on imports of high-tech goods.[34]

Let us now assume that $\xi_h = \bar{\xi}$, so that the home country has set its tariff as high as possible. In this case, the foreign country cannot set a higher tariff than the one imposed by the home

[32] Clearly, this strategy delivers higher welfare gains compared to setting $\xi_f = \xi_h$. By setting $\xi_f = \xi_h$, in fact, the foreign country would suffer the same productivity losses, while enjoying smaller technological rents compared to setting ξ_f slightly below ξ_h.

[33] Recall that we assumed each country to be endowed with $\bar{I}$ units of the innovation good, the sales of which enter GDP (equation (19)). As the foreign country retaliates, the global price of the innovation good becomes

$$p_t^I = \frac{\eta\varpi}{R-\eta\rho}(1+\xi_h).$$

This is lower than in the case of no retaliation, and hence foreign GDP, and along with it, consumption, declines.

[34] There is also a third, more subtle effect. Retaliating lowers the price of the innovation good, so reducing the value generated by its sales. This effect is stronger the higher the tariff imposed by the rest of the world.

country. Hence, if it chooses to retaliate, the foreign country will set $\xi_f = \xi_h = \bar{\xi}$, so as to retain the same technological rents as in the free-trade steady state. It follows that the foreign country chooses to retaliate if

$$\sum_{t=0}^{+\infty} \left(\frac{g}{R}\right)^t \Delta^{nr}(gdp_{f,t} - p_t^I I_{f,t}) = \frac{R}{R-\rho} \left(\underbrace{\varpi(1+\bar{\xi}) \left(\frac{R-\eta g}{R-\eta\rho} \frac{R-\rho}{R-g} - 1 \right) a_{f,0}}_{\text{technological rents}} \right.$$
$$\left. - \underbrace{(1-\varpi) \left(1 - \frac{\bar{\xi}^\alpha - \alpha\bar{\xi}}{1-\alpha} \right) a_{h,0}}_{\text{labor income}} - \underbrace{\frac{R-\rho}{R-g}(1-\bar{\xi}) \frac{\eta\varpi\bar{I}}{R-\eta\rho}}_{\text{sales of innovation good}} \right) > 0, \quad (31)$$

otherwise the foreign country does not retaliate and $\xi_f = 1$. Notice that this condition is almost identical to (30), evaluated at $\xi_f = \xi_h = \bar{\xi}$. The only difference is that by retaliating the foreign country defends its technological rents, but does not attract innovation goods from the home country. This explains the absence of $a_{h,0}$ in the term capturing the technological rents.

We can now summarize the optimal retaliation strategy adopted by the foreign country. If condition (31) holds, i.e. if losing technological rents has a large impact on welfare, it is optimal for the foreign country to retaliate for any value of ξ_h. If condition (31) does not hold, there exists a threshold value for ξ_h, let's call it ξ^*, such that it is optimal for the foreign country to retaliate if and only if $\xi_h > \xi^*$. The threshold satisfies $\xi^* = \max\left(\tilde{\xi}, \bar{\xi}\right)$, where $\tilde{\xi}$ is the value of ξ_h that makes expression (30) equal to zero. Intuitively, the threshold ξ^* is defined as the value of ξ_h that makes the foreign country indifferent between retaliating or not.[35] When indifferent, we assume that the foreign country does not retaliate.

One immediate implication of this retaliation strategy is that a Stackelberg equilibrium with free trade does not exist, because expression (30) is always positive when $\xi_h = 1$. Indeed, if the rest of the world operates under free trade, a country can gain technological rents by placing an infinitesimally small tariff on imports of high-tech goods. The impact of this strategy on welfare is clearly positive, because higher technological rents bring positive welfare gains, while the cost of this strategy in terms of lower labor productivity is infinitesimally small. This means that, absent international cooperation, the temptation of national governments to impose tariffs on foreign high-tech goods is too strong for free trade to be an equilibrium.[36]

5.2 Strategic trade wars

We now derive the behavior of the Stackelberg leader, that is the home country. From now on, we will streamline the analysis by assuming that in the initial free-trade steady state the home country is at least as technologically advanced as the foreign one ($a_{h,0} \geq a_{f,0}$). Relaxing this assumption would not be difficult, but it would make the analysis more cumbersome. Moreover,

[35] To be precise, if $\xi^* = \bar{\xi}$ then the foreign country is strictly better off by not retaliating.

[36] This result hinges on the assumption of no transport cost on the innovation good (see Appendix B).

this case squares well with our interest in understanding the impact of the tariffs recently imposed by the United States, arguably one of the world's technological leaders.

It turns out that the shape of the equilibrium crucially depends on whether condition (31) holds. Let us start by assuming that it doesn't, which corresponds to a scenario in which the technological rents are not too large. In this case, the home country will wage a strategic trade war. That is, the home country will set its tariff just high enough to discourage retaliation by the foreign country.

More precisely, if condition (31) is violated it will be optimal for the home country to set $\xi_h = \xi^*$.[37] This strategy, in fact, ensures that the home country enjoys all the technological rents, while minimizing the productivity losses due to reduced access to foreign high-tech goods. The equilibrium is then asymmetric. The home country imposes import tariffs and becomes the technological leader. The foreign country is hurt by these tariffs, but has no incentives to retaliate. The world thus falls in what looks like a unilateral trade war, in which one country disrupts international trade to boost its technological rents.

This unilateral trade war has a strategic nature. From the point of view of a naive observer, it would look like the home country is imposing excessively high tariffs. In fact, as we have observed in Section 4.1, if the rest of the world maintains free trade a country can appropriate all the technological rents by imposing an infinitesimally small tariff. But this logic overlooks the possibility that the rest of the world retaliates. The high tariffs imposed by the home country serve precisely the strategic objective of preventing retaliation from the rest of the world.

The numerical example discussed in Section 4.2 corresponds to a Stackelberg equilibrium in which the home country implements a strategic import tariff equal to 52.7%. As we have seen, both the foreign country and the global economy as a whole experience significant welfare losses as a result of the strategic trade war waged by the home country.

5.3 Full-blown trade wars

We now describe what happens when condition (31) holds. Intuitively, in this scenario technological rents are so valuable that the foreign country is willing to retaliate for any trade policy set by the home country. The result is a full-blown trade war, in which both countries impose the maximum possible tariff and $\xi_h = \xi_f = \bar{\xi}$. This trade war has no winner. Since both countries tax imports at the same rate, in fact, there is no effect on the distribution of technological rents. Still, a full-blown

[37] Clearly, it cannot be optimal for the home country to set $\xi_h < \xi^*$, because this would deliver higher productivity losses, without any gain in terms of higher technological rents, compared to $\xi_h = \xi^*$. Now suppose that the home country sets $\xi_h > \xi^*$. In this case, the home country will lose all the technological rents to the foreign one, while limiting the productivity losses with respect to $\xi_h = \xi^*$. Hence, the gains from this strategy are maximized when $\xi_h = 1$. One can show that the home country gains from setting $\xi_h = \xi^*$ compared to $\xi_h = 1$ if

$$2\varpi\left(\frac{R-\eta g}{R-\eta\rho}\frac{R-\rho}{R-g}-1\right)(a_{f,0}+a_{h,0}) > (1-\varpi)\left(1-\frac{(\xi^*)^{\alpha}-\alpha\xi^*}{1-\alpha}\right)a_{f,0}.$$

Using $a_{h,0} \geq a_{f,0}$, expression (30), and the definition of ξ^*, one can see that this inequality always holds. Intuitively, this is the case because by setting a positive tariff the Stackelberg leader reduces the value of appropriating technological rents for the follower.

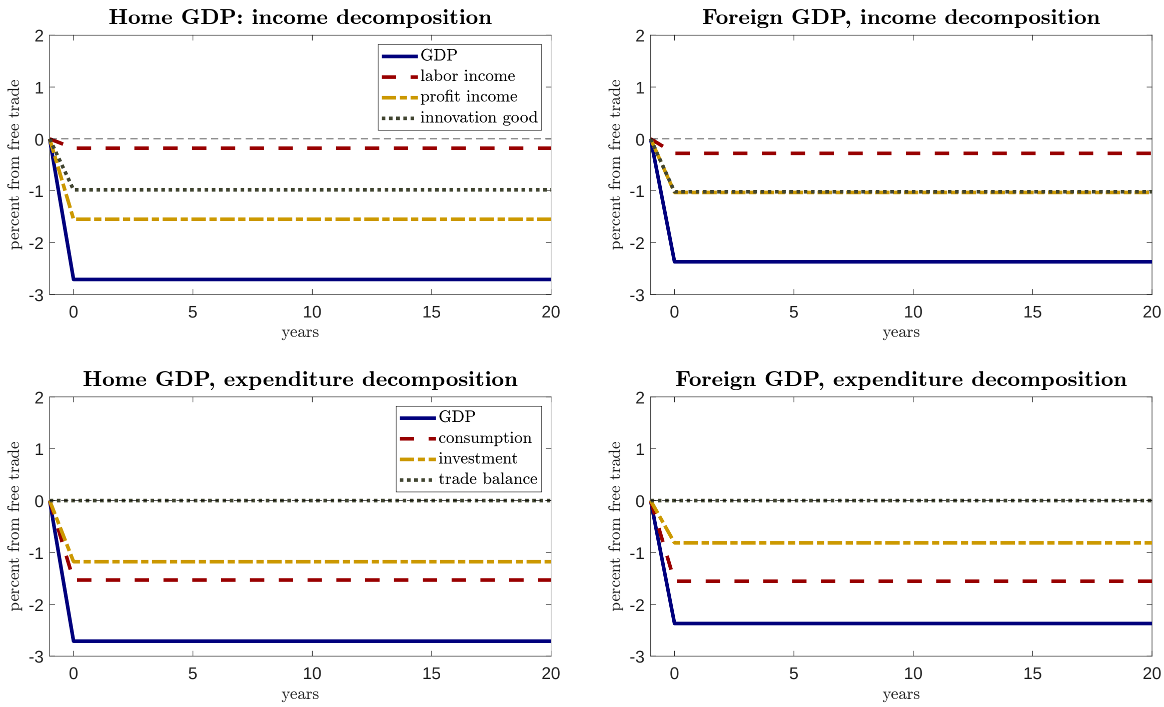

Figure 4: A full-blown trade war. Notes: GDP is expressed as percent deviation from the initial free-trade steady state. The components of GDP are expressed as percent deviation from their respective steady states, weighted by their respective steady state shares in GDP.

trade war is the only possible equilibrium, because the home country anticipates that if it were to set $\xi_h > \bar{\xi}$ it would lose all the technological rents to the foreign country.

In a full-blown trade war, the economy immediately jumps on a new steady state, in which both countries suffer a GDP loss. More precisely, relative to the initial free-trade steady state, GDP in country i behaves according to

$$\Delta^{ft} gdp_{i,t} = -(1-\varpi)\left(1 - \frac{\bar{\xi}^{\alpha} - \alpha\bar{\xi}}{1-\alpha}\right) a_{-i,0} - \varpi(1-\bar{\xi})a_{i,0} - (1-\bar{\xi})\frac{\eta\varpi\bar{I}}{R-\eta\rho}.$$

The first term reflects the negative impact of reduced imports of high-tech goods on productivity, the second term the loss of profits from exports of high-tech goods, while the last term the drop in the value of the innovation good. Clearly, lower GDP translates into lower consumption and welfare in both countries.

It is also instructive to look at the impact of a full-blown trade war on global GDP

$$\Delta^{ft}(gdp_{h,t} + gdp_{f,t}) = -\left((1-\varpi)\left(1 - \frac{\bar{\xi}^{\alpha} - \alpha\bar{\xi}}{1-\alpha}\right) + \varpi(1-\bar{\xi})\right)(a_{h,0} + a_{f,0}) - 2(1-\bar{\xi})\frac{\eta\varpi\bar{I}}{R-\eta\rho}.$$

In contrast with the case of unilateral trade wars, the loss in global GDP triggered by a full-blown trade war turns out to be permanent. The reason is that, in a unilateral trade war, the rise in the productivity of high-tech goods produced by the country imposing the tariff mitigates over time the impact of trade restrictions on global GDP. This effect does not operate in full-blown trade wars, which explains why they trigger permanent global output losses. In fact, as we discuss in

Appendix B, with an elastic supply of the innovation good a full-blown trade war also leads to a drop in global productivity, which amplifies the global output losses.

Figure 4 shows an example of a full-blown trade war. To construct this figure, we have used the same baseline parametrization described in Section 4.2. The only exception is that we impose an upper bound on the tariff rate low enough, such that it is always optimal for the foreign country to retaliate. In particular, we set $\bar{\tau} = 25.6\%$, which is the highest possible value of $\bar{\tau}$ consistent with a full-blown trade war under our baseline parametrization.[38] The result of this full-blown trade war is a substantial drop in GDP and consumption in both countries. The associated welfare losses are equal to a 1.67% (for the home country) and a 1.65% (for the foreign country) permanent decline in consumption in the initial steady state.

6 Tariffs on innovation goods

The tariffs that we considered thus far are of a particular form. Indeed, we have studied tariffs on imports of high-tech goods, designed to reduce the demand for innovation inputs from foreign high-tech firms. We now study what happens when the government taxes the imports of innovation inputs. This scenario captures the notion that, in practice, it may be hard for a government to discriminate between imports of high-tech and innovation goods.[39] Moreover, this seems relevant to understand the impact of some policies recently introduced in the US, such as the fees imposed on foreign high-skilled workers to obtain visas. We will argue that taxing innovation inputs may severely hinder the usefulness of trade policy as a way to gain technological hegemony.

Suppose that the home country combines the tariff on imports of high-tech goods studied in the previous section with a tariff on imports of foreign innovation goods. This tariff is such that a home importer of foreign innovation goods has to pay to the domestic government $\tau_h^I p_f^I$ for each unit imported, where τ_h^I denotes the tariff and p_i^I the price of the innovation good sold by agents belonging to country i.[40] The revenue from the tariff is fully rebated to domestic agents through lump-sum transfers. Throughout this section, we will assume that the foreign country maintains free trade ($\xi_f = 1$).

Naturally, this tariff depresses the return from importing foreign innovation goods for home high-tech firms. But it turns out that its the macroeconomic impact depends crucially on the

[38] Notice that setting $\bar{\tau} < 52.7\%$ would not be enough to trigger a full-blown trade war. For $25.6\% < \bar{\tau} < 52.7\%$, indeed, the home country would set a strategic tariff equal to $\bar{\tau}$, and the foreign country would not have an incentive to retaliate.

[39] Just think about computers, which are both a high-tech good, since their development requires substantial investments in R&D, as well as an input to innovation activities.

[40] Assuming that the tariff is paid by the foreign exporter of innovation goods would not change the analysis, but it would make the notation more complicated.

magnitude of the tariff. In particular, let us define the threshold[41]

$$\bar{\tau}_h^I \equiv \frac{1-\xi_h}{1+\xi_h}. \tag{32}$$

If $\tau_h^I \leq \bar{\tau}_h^I$, then - in spite of the tariff - it is still profitable for home high-tech firms to invest the full global endowment on innovation goods, so that $I_{h,t} = 2\bar{I}$. The tariff, however, depresses the price of foreign innovation goods, which is now given by the no-arbitrage condition

$$p_f^I(1+\tau_h^I) = p_h^I = \frac{2\eta\varpi}{R-\eta\rho}.$$

Due to this effect, a tariff on foreign innovation goods actually increases the technological rents enjoyed by the home country. In fact, the increase in welfare that the home country experiences from the combined effect of the tariffs on imports of high-tech and innovation goods is

$$\sum_{t=0}^{+\infty}\left(\frac{g}{R}\right)^t \Delta^{ft}(gdp_{h,t} - p_h^I I_{h,t})$$
$$= \frac{R}{R-\rho}\left(2\varpi\left(\frac{R-\eta g}{R-\eta\rho}\frac{R-\rho}{R-g} - 1\right)a_{f,0} - (1-\varpi)\left(1 - \frac{\xi_h^\alpha - \alpha\xi_h}{1-\alpha}\right)a_{f,0} + \frac{R-\rho}{R-g}\frac{\tau_h^I}{1+\tau_h^I}\frac{2\eta\varpi\bar{I}}{R-\eta\rho}\right).$$

This expression is identical to (28), except for the last term on the right-hand side. This term captures the additional technological rents caused by the depressive impact of the tariff τ_h^I on the price of imported innovation goods. These rents are fully extracted from the foreign country, which experiences welfare losses of exactly the same size.

In essence, taxing imports of innovation inputs manipulates the terms of trade in favor of the home country, and so these insights are directly related to the well-studied terms of trade effects of trade policies. The only twist is that this trade policy acts on the relative price of the inputs to the innovation process, while most of the literature focuses on the terms of trade of finished manufactured goods.

But what if $\tau_h^I > \bar{\tau}_h^I$? In this case, the tariff is so high that importing innovation goods is no longer profitable for high-tech firms located in the home country. Each country then absorbs its own endowment of innovation goods, and $I_{h,t} = I_{f,t} = \bar{I}$. The consequence is that this type of trade policy fails to foster technology hegemony for the home country. Even worse, to the extent that the home country is initially technologically more advanced compared to the foreign one ($a_{h,0} > a_{f,0}$), the drop in imports of innovation inputs will cause a gradual a decline in innovation activities and technological rents.

More precisely, suppose that the economy starts from a free-trade steady state in which $a_{h,0} >$

[41] To derive this threshold, consider that home high-tech firms are willing to import foreign innovation goods only if $p_f^I(1+\tau_h^I) \leq \frac{2\eta\varpi}{R-\eta\rho}$. Foreign high-tech firms, instead, are willing to invest in innovation if $p_f^I \leq \frac{(1+\xi_h)\eta\varpi}{R-\eta\rho}$. It follows that if $\tau_h^I \leq \bar{\tau}_h^I$ then home high-tech firms absorb the entire global endowment of foreign innovation goods, while if $\tau_h^I > \bar{\tau}_h^I$ then foreign endowment of innovation goods is fully utilized by foreign high-tech firms. Of course, due to the tariff on foreign high-tech goods, it is not profitable for foreign firms to purchase innovation inputs from home agents.

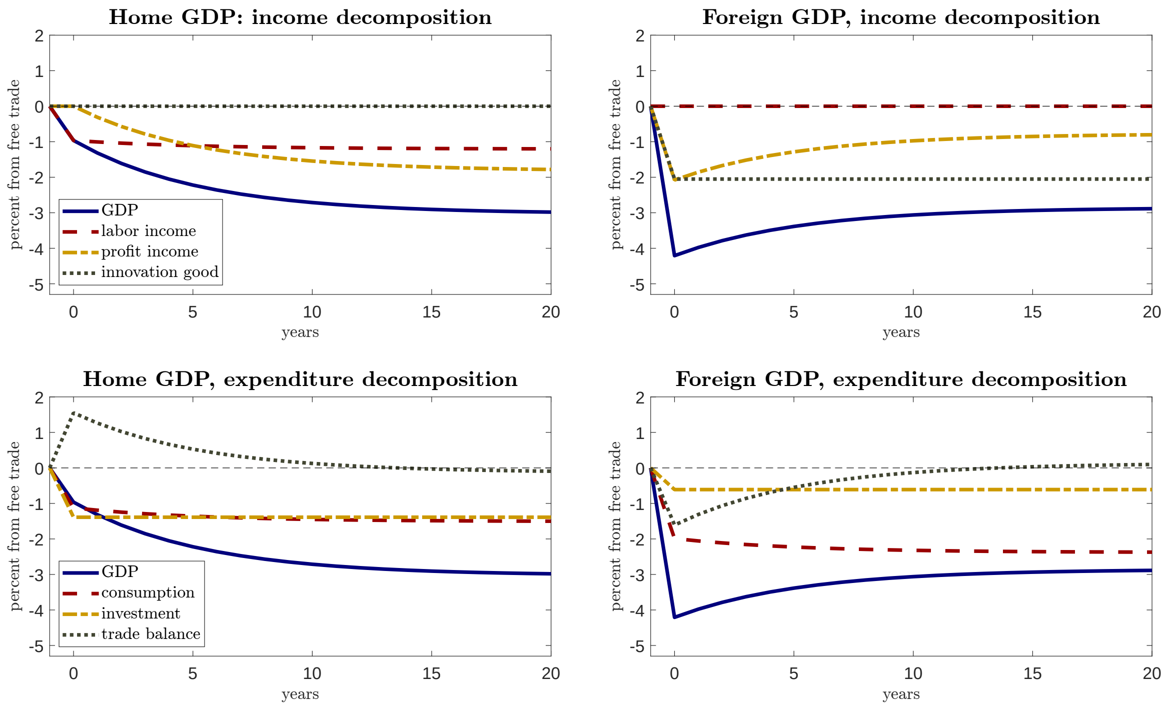

Figure 5: Impact of import tariffs on all imported goods. Notes: GDP is expressed as percent deviation from its initial free-trade steady state. The components of GDP are expressed as percent deviation from their respective steady states, weighted by their respective steady state shares in GDP.

$a_{f,0}$. Now imagine that the home country imposes both a tariff on high-tech goods ($\xi_h < 1$) and a large tax on imports of innovation goods ($\tau_h^I > \bar{\tau}_h^I$). This trade policy induces home firms to stop importing innovation goods ($I_{h,t} = \bar{I}$), and $a_{h,t}$ declines according to

$$a_{h,t} = \left(\frac{\rho}{g}\right)^t a_{h,0} + \left(1 - \left(\frac{\rho}{g}\right)^t\right) \frac{\bar{I}}{g - \rho},$$

until it reaches its new long run value of $\bar{I}/(g - \rho)$.

Relative to the free-trade steady state, home GDP is given by

$$\Delta^{ft} gdp_{h,t} = -(1 - \varpi)\left(1 - \frac{\xi_h^\alpha - \alpha\xi_h}{1 - \alpha}\right)\left(a_{f,0} + \left(1 - \left(\frac{\rho}{g}\right)^t\right)\left(a_{h,0} - \frac{\bar{I}}{g - \rho}\right)\right) - 2\varpi\left(1 - \left(\frac{\rho}{g}\right)^t\right)\left(a_{h,0} - \frac{\bar{I}}{g - \rho}\right).$$

Intuitively, GDP declines both because of the productivity drop due to lower imports of foreign high-tech goods, but also because the quality of domestic high-tech goods declines. Moreover, home high-tech firms suffer a loss of profits. These income losses depress consumption and welfare in the home country.

Figure 5 shows these dynamics. This figure is constructed using our baseline parametrization, and assuming that the home country taxes imports of foreign innovation goods at the same rate as the tariff on foreign high-tech goods. This trade policy triggers a large permanent drop in home

GDP, which translates into a welfare loss equal to a 1.61% permanent reduction in consumption in the initial free-trade steady state. One interesting observation is that this trade policy does improve the home trade balance, due to lower consumption and investment. However, these trade balance surpluses are a symptom of weakness, rather than strength of the home economy.

What about the impact on the foreign country? The foreign country not only experiences an income drop from lower high-tech profits. Now it also suffers income losses due to the adverse effect of the home trade policy on the price of the foreign innovation good. The result is a welfare loss equal to 2.50% of consumption in the initial free-trade steady state. Clearly, this trade war waged by the home country has no winners.

7 Conclusion

Our theory suggests that countries have an incentive to use import tariffs to boost innovation activities and gain a position of technological hegemony. Our model, however, highlights several potential limitations to this strategy. First, even if successful, the trade policies that we have studied impose welfare losses on the rest of the world. Second, trade policies may backfire even for the country imposing them, if they are not well designed, or if the rest of the world retaliates. In sum, while our analysis suggests that tariffs can have an impact on the geographical allocation of innovation activities, it also indicates that imposing import tariffs to boost domestic high-tech sectors is a risky strategy, which can easily backfire. Other policy instruments, such as subsidies to private R&D or public R&D programs, are better suited to promote innovation and technological development.

We conclude by mentioning two promising areas for future research. First, our model could be used to study the international spillovers triggered by other policy interventions, such as subsidies to investment in innovation and other industrial policies.[42] Second, our model assumes a representative agent, which earns income both from labor and profits. Introducing a more realistic income distribution is likely to lead to interesting results. In our framework, in fact, import tariffs boost profits, thus benefiting capitalists, and depress labor income, hurting workers. If capitalists represent a small fraction of the population, this observation weakens the welfare case for import tariffs. However, capitalists may have a better ability to influence the political process, and so the design of trade policies. Extending our model to study these political economy considerations is a very interesting area for future research.

[42] See Ferrari and Ossa (2023) for a recent study on the spillovers triggered by subsidies to firms' relocation.

Appendix

A Analytical derivations

A.1 Optimal investment in innovation by private firms

Firms choose investment to maximize dividends

$$\max_{\{I_t^j\}_t} \sum_{t=0}^{+\infty} \left(\frac{\eta}{R}\right)^t \left(\varpi A_t^j (1+\xi_{-i}) - P_t^I I_t^j\right),$$

subject to the constraints

$$\begin{aligned} A_{t+1}^j &= \rho A_t^j + A_t^* I_t^j, \\ I_t^j &\geq 0. \end{aligned}$$

The Lagrangian of this problem is given by

$$\mathcal{L} = \sum_{t=0}^{+\infty} \left(\frac{\eta}{R}\right)^t \left\{ \left(\varpi A_t^j (1+\xi_{-i}) - P_t^I I_t^j\right) - \gamma_t (A_{t+1}^j - \rho A_t^j - A_t^* I_t^j) + \iota_t I_t^j \right\},$$

where γ_t and $\iota_t \geq 0$ denote the Lagrange multipliers on the two constraints.

The first order conditions with respect to I_t^j and $A_{j,t+1}^j$ are

$$P_t^I = \gamma_t A_t^* + \iota_t$$

$$\gamma_t = \frac{\eta}{R}(\varpi(1+\xi_{-i}) + \rho\gamma_{t+1}).$$

Combining these two expressions one obtains

$$\frac{P_t^I - \iota_t}{A_t^*} = \frac{\eta}{R}\left(\varpi(1+\xi_{-i}) + \rho \frac{P_{t+1}^I - \iota_{t+1}}{A_{t+1}^*}\right).$$

Iterating this equation forward gives

$$\frac{P_t^I - \iota_t}{A_t^*} = \sum_{\zeta=1}^{+\infty} \left(\frac{\eta}{R}\right)^\zeta \rho^{\zeta-1} \varpi (1+\xi_{-i}).$$

Using the fact that $\iota_t \geq 0$ gives the expression in the main text.

B Model extensions

B.1 Trade costs on innovation inputs

Our baseline model assumes that innovation goods can be traded across countries frictionlessly. This feature implies that an infinitesimal difference in the return on innovation across countries triggers the reallocation of the entire stock of innovation goods. To make the model more realistic, in this Appendix we introduce trade costs for innovation goods.

We start by considering a case where the trade cost per unit of innovation good shipped is constant. Specifically, we assume that, for each unit of innovation good imported, the importing firm needs to pay the foreign owner of the innovation good $p^I(1+\kappa)$ units of the consumption good ($\kappa > 0$). This specification captures the idea that a premium needs to be paid to attract innovation goods from abroad. Thinking of innovation goods as skilled labor, for instance, this premium may capture the disutility loss that foreign skilled workers experience from leaving their home country.

Constant trade cost. Suppose that two countries are initially in a symmetric free trade steady state, in which each country absorbs its own stock of innovation goods ($I_i = \bar{I}$ for $i = h, f$). Because there is no trade in innovation goods initially, the price of innovation goods in both countries is $p^I_{ft} = \frac{2\eta\varpi}{R-\eta\rho}$. Assume now that the home country imposes import tariffs ($\xi_h < 1$), while the foreign one remains open to free trade ($\xi_f = 1$). As before, profits by foreign exporters fall to the level $\varpi(1+\xi_h)$. Because of lower profits, the highest price that foreign firms are willing to pay for innovation goods is

$$\frac{\eta\varpi(1+\xi_h)}{R-\eta\rho}.$$

Compare this with the price that home firms are willing to pay to import innovation goods from the foreign country, given by

$$\frac{1}{1+\kappa}\frac{\eta\varpi 2}{R-\eta\rho}.$$

The price that home firms are willing to pay is adjusted by the factor $1/(1+\kappa)$, because these firms effectively pay $(1+\kappa)$ times the price of innovation goods to import them, due to the premium that needs to be paid per unit of innovation good imported.

This reveals that as long as

$$1+\xi_h > \frac{2}{1+\kappa}, \tag{B.1}$$

that is as long as tariffs are not too large, foreign innovation goods will stay with the foreign firms, and will not be exported to the home country. In this model extension, therefore, it takes a strictly positive difference in the return on innovation across countries to induce innovation goods to move across countries.

As long condition (B.1) holds, the pattern of innovation across countries is not affected by the home tariffs, as both countries still absorb their own endowment of innovation goods. This does not imply, however, that the tariffs imposed by the home country have no macroeconomic effects.

In fact, tariffs still lead to lower imports of foreign high-tech goods by home firms, implying a drop in home productivity, output, consumption, and therefore welfare. In fact, upon the imposition of tariffs, the economy jumps immediately in a new steady state, in which home GDP is given by

$$\Delta^{ft} gdp_h = -(1-\varpi)\left(1 - \frac{\xi_h^{\alpha} - \alpha\xi_h}{1-\alpha}\right) a_{h,0},$$

and is therefore decreasing in home tariffs (Δ^{ft} continues to denote deviation from the initial free-trade steady state). Foreign GDP also declines, driven by two effects. The first is a decline of profits by foreign exporters, as they sell less products to the home market. Second, because the price of the innovation good declines in the foreign country, this likewise leads to lower GDP. In fact, after the imposition of tariffs, GDP in the foreign country is now given by

$$\Delta^{ft} gdp_f = -\varpi(1-\xi_h)a_{f,0} - (1-\xi_h)\frac{\eta\varpi\bar{I}}{R-\eta\rho}.$$

While they are not affecting the pattern of innovation, the tariffs imposed by home therefore imply that GDP and welfare decline in both countries.

What happens when condition (B.1) is violated? In this case, the profits by foreign firms are depressed by so much that innovation goods flow to the home country, despite the presence of trade costs. The analysis is then identical to the one from our baseline model, i.e. innovation goods flow to the home country setting off transitional dynamics, improving home GDP over the medium run. In particular, the model still has the property that the entire stock of foreign innovation goods flows to the home country.[43]

Convex trade costs. The constant trade costs specification captures the idea that a large-enough return differential may be needed in order to induce innovation goods to move. However, conditional on the return differential being large enough, it still implies that the entire stock of innovation goods flows to the other country.

In practice this process is likely subject to decreasing returns. For instance, the premium needed to induce innovation goods to move across borders may be heterogeneous across the suppliers of innovation goods. In particular, some goods may only move when the premium paid is particularly large.[44] Second, when the innovation technology is curved - rather than linear as in our baseline model - then some innovation goods will always stay with the foreign country, because the return on innovation becomes arbitrarily large as the innovation intensity approaches zero.

We capture this notion with a flexible specification in which the trade cost is an increasing function of the amount of innovation goods shipped. We assume that, in order to import innovation good $i \in [0, \bar{I}]$ from the foreign country, the importing firm needs to pay the foreign owner of the

[43] What about the premium κ that is now paid in equilibrium? Home firms' total spending on foreign innovation goods - inclusive of the premium - is still given by $\frac{\eta\varpi 2}{R-\eta\rho}$ per unit of innovation good bought. Because innovation spending is the same as in our baseline model, the equilibrium path for consumption is also identical.

[44] Thinking of skilled labor, moving costs may be heterogeneous across workers, as might be the taste to move to another country.

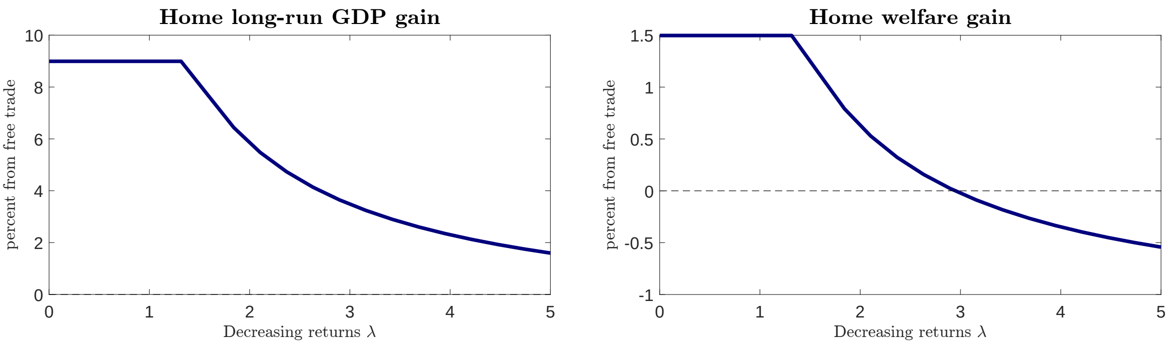

Figure 6: Decreasing returns to flows of innovation good. Notes: The figure shows the long-run GDP and welfare gains in the home country after the imposition of $\tau_h = 52.7\%$ on foreign intermediate goods, assuming that the foreign country does not retaliate, for varying degrees of λ. All other parameters are as in Figure 3 - except that here we assume a symmetric initial steady state - plus we set $\kappa = 0.1$.

innovation good $p^I(1+\kappa(i))$ units of the consumption good, where

$$\kappa(i) = \kappa \exp(\lambda(I_{h,t} - \bar{I})), \quad \kappa, \lambda \geq 0. \tag{B.2}$$

This specification nests our baseline model when $\kappa = 0$, and also the constant-premium specification, which corresponds to $\kappa > 0$ and $\lambda = 0$.

We can see that, as long as $1 + \xi_h > \frac{2}{1+\kappa}$, foreign innovation goods will not be shipped to the home country at all, as in the constant-premium specification. In turn, when $1 + \xi_h < \frac{2}{1+\kappa \exp(\lambda \bar{I})}$, then the entire amount of foreign innovation goods will be shipped to the home country ($I_{h,t} = 2\bar{I}$). Finally, for intermediate tariffs, the amount of innovation goods shipped is determined by the break-even condition

$$1 + \xi_h = \frac{2}{1 + \kappa \exp(\lambda(I_{h,t} - \bar{I}))}, \tag{B.3}$$

so that $\bar{I} < I_{h,t} < 2\bar{I}$.

To study this extension, we go back to our numerical example from Figure 3. Recall that in this figure, the home country imposes a tariff rate of $\tau_h = 52.7\%$ on imports of foreign intermediate goods, and the foreign country does not retaliate. We study the same scenario here, but consider different degrees of decreasing returns λ. Our baseline model corresponds to $\lambda = 0$, in which case the tariffs improve both home long-run GDP and welfare

Figure 6 shows the result.[45] When $\lambda = 0$, long-run GDP rises by around 9%, and welfare rises by around 1.5%, expressed in permanent consumption units of the free-trade steady state. As λ rises, both numbers are not affected initially. This reflects that the tariff rate is quite high, and decreasing returns are not strong enough to prevent that the entire stock of innovation goods flows to the home country.[46] Once λ becomes large enough, however, not all of foreign innovation goods

[45] All parameters are as in Figure 3, with one exception. In the model with trade costs, the initial steady state is necessarily symmetric, i.e. $a_{h,0} = a_{f,0} = \bar{I}/(g - \rho)$. In Figure 3, instead, we started from an asymmetric steady state, where the home country was technologically more advanced than the foreign one. In addition, in Figure 6 we set $\kappa = 0.1$, so that the premium paid on the first unit of innovation good to move is 10%.

[46] Over this region, the inequality $1 + \xi_h < \frac{2}{1+\kappa \exp(\lambda \bar{I})}$ still holds, as we explained above.

flow to the home country, and the GDP and welfare gains triggered by the tariffs start to become smaller. The GDP gains become smaller, because investment in the home country rises by less when the tariffs trigger a smaller reallocation of innovation goods toward to the home country. Finally, note how the welfare gains turn even negative when the degree of decreasing returns is high enough. Over this range, the costs of tariffs outweigh the gains, because the gains in terms of higher long-run GDP and innovation rents are too small to compensate for the distortions (less imports of foreign high-tech goods, lowering home productivity) associated with tariffs.

In the main text we cautioned against the use of tariffs to try to attract foreign innovation goods, on two grounds. First, the foreign country may retaliate. Second, to the extent that tariffs apply also to innovation goods themselves, they will surely backfire. Here we discussed a third reason why imposing tariffs may backfire. Even if they are perfectly designed (they do not apply to innovation goods), and even if the foreign country does not retaliate, they will lower welfare in case a large stock of innovation goods cannot be attracted easily from abroad, i.e. in presence of decreasing returns.

B.2 Elastic supply of innovation goods

Our analysis introduces the notion of innovation goods, defined as special inputs that are needed in the innovation process. Moreover, we assumed that innovation goods are internationally mobile, so that countries can compete to attract innovation goods to foster their domestic high-tech sectors. As we explained in the text, one example of the innovation goods that we have in mind are high-skilled workers, who are clearly critical in the innovation process and who are also internationally mobile.

For simplicity, however, in our baseline model we have treated the supply of innovation goods as an endowment and thus as inelastic to global economic conditions. To make the model more realistic, in this Appendix we micro-found the supply of innovation goods more explicitly. This implies, in particular, that the supply of innovation goods may now respond to changes in economic conditions.

Changes to economic environment. In the main text we assumed that each household supplies one unit of innovation goods inelastically. We now assume that households' supply of innovation goods carries a utility cost that is increasing and convex in the amount of innovation goods supplied. Specifically, households' welfare is now

$$\sum_{t=0}^{\infty} C_{i,t} - \phi A_t^* \frac{(I_{i,t}^s)^{1+\varphi}}{1+\varphi}, \quad \phi, \varphi > 0.$$

We scale the disutility of supplying innovation goods with the technology frontier A_t^*, to guarantee the existence of a balanced growth path.

As before, when selling the innovation good, households receive the price P_t^I. The supply curve of innovation goods then has the shape

$$\phi A_t^*(I_{i,t}^s)^\varphi = P_t^I, \tag{B.4}$$

where consumption does not appear because the utility function is linear in consumption (no wealth effects). Because the innovation good is traded frictionlessly across borders, the price of innovation goods P_t^I does not carry a country index i. From the last equation, this also implies that the supply of innovation goods is identical across country, $I_{h,t}^s = I_{f,t}^s = I_t^s$. Notice that, when $\varphi \to \infty$, our baseline model reappears, as households in both countries supply inelastically $I_t^s = 1$.

One possible interpretation of this formulation is that innovation goods correspond to specialized (high-skilled) labor. In this case, the term $-\phi A_t^* \frac{(I_{i,t}^s)^{1+\varphi}}{1+\varphi}$ captures the disutility from supplying skilled labor, and (B.4) captures the labor supply curve, with P_t^I denoting the wage rate that households receive from supplying skilled labor. Also, because the utility function is linear in consumption, we would obtain a very similar reduced form in case innovation goods were produced from final consumption goods, with a concave production function.[47]

The problem of firms is unchanged relative to our baseline model. In particular, the first order condition is still given by (10):

$$\frac{P_t^I}{A_t^*} \geq \sum_{\zeta=1}^{+\infty} \frac{\eta^\zeta \rho^{\zeta-1}}{R^\zeta} \varpi \left(1 + \xi_{-i}\right), \qquad S_t^j \geq 0,$$

with one expression holding as a strict equality.

Initial steady state. We focus on an initial steady state where both countries are fully open ($\xi_h = \xi_f = 1$). In this steady state, firms' investment first order condition pins down the (normalized) price of innovation goods

$$p^I = \frac{2\eta\varpi}{R - \eta\rho}.$$

The supply curve in steady state is

$$\phi(I^s)^\varphi = p^I.$$

Solving for I^s

$$I^s = \left(\frac{1}{\phi}\frac{2\eta\varpi}{R - \eta\rho}\right)^{\frac{1}{\varphi}}, \tag{B.5}$$

which replaces $I^s = \bar{I}$. All the other steady state conditions are the same as in our baseline model.

Unilateral tariffs. Assume that the home country imposes tariffs on imports of intermediate goods, and the foreign country does not retaliate. Along the lines of the analysis in the main text, this policy implies that home firms absorb all of the global supply of innovation goods, while foreign firms stop innovating. Because home firms' profits are unaffected by the tariffs, they are

[47] The only difference would be that the market for innovation would not have a separate market clearing condition, but would instead become part of goods market clearing for consumption.

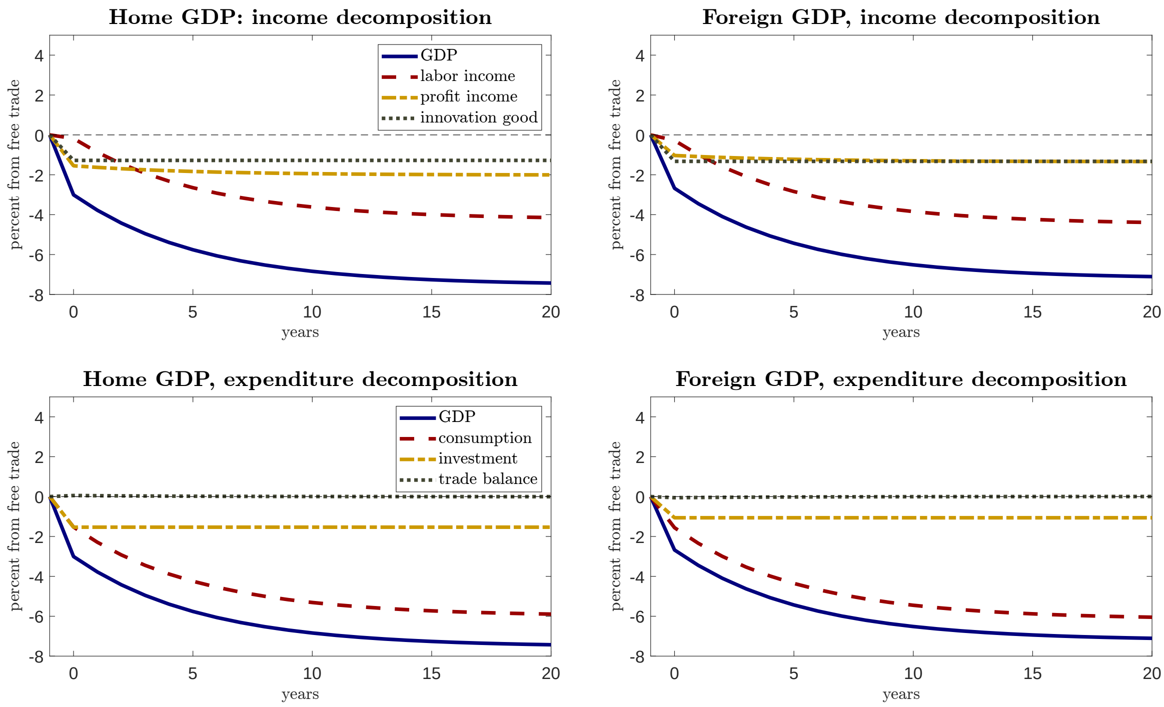

Figure 7: Full-blown trade war with elastic supply of innovation goods. Notes: The Figure is constructed in an analogous way as Figure 4, except that the supply of innovation goods is endogenous.

still willing to pay the same price for innovation goods as before the imposition of tariffs. This implies that the supply of innovation goods remains in steady state in both countries, independent of the size of tariffs. Hence, unilateral tariffs trigger exactly the same dynamics as in our baseline model.

Retaliation. A difference arises once the foreign country retaliates and the economy falls in a full-blown trade war. In this case, as we explained in the main text and illustrated in Figure 4, the price of innovation goods declines globally, reflecting reduced incentives for all firms to conduct innovation. Once the supply of innovation goods is endogenous, the reduced price of innovation goods entails a decline in their supply, leading to an additional decline in global investment. Hence the model with elastic supply of innovation goods predicts an even deeper recession than the model with inelastic supply.

We illustrate this effect by repeating the experiment of full-blown trade war from Figure 4, but now assuming that the supply of innovation goods is endogenous. To make results comparable, we choose the same parameters as in our baseline model. In particular, we set $\phi = .8696$ so that $I^s = 1$ in steady state, as in our baseline model. To calibrate the elasticity of the supply of innovation goods with respect to their price, we pick a value $\varphi = 3$. This corresponds to a Frisch elasticity of labor supply of $1/3$, once we adopt the interpretation that innovation goods reflect skilled labor supplied by households.

The result is in Figure 7, which is structured in the same way as Figure 4. As we can see, the fact that the supply of innovation goods is endogenous makes the implications of the full-blown trade war even more dramatic. The decline in GDP, which was around 3% in the case with inelastic supply of innovation goods, now becomes close to 8% over the long term. This is driven by lower long-run productivity, due to lower investment in both countries. In fact, in this numerical example, the global supply of innovation goods drops from 2 before the trade war to 1.9 during the trade war, or a decline of around 5%. The welfare implications are likewise much larger than in our baseline model. While the full-blown trade war triggered welfare losses of 1.67% (home country) and 1.65% (foreign country) in our baseline model - both expressed in units of permanent consumption equivalents - the corresponding numbers are 6.16% and 6.15% in the model with elastic supply of innovation goods.

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