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Intellectual property, tariffs, and international trade dynamics☆

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ABSTRACT

The emergence of global value chains leads not only to a magnification of trade in intermediate inputs, but also to extensive technology diffusion. Moreover, the lack of enforcement of intellectual property rights has recently become a subject of debate in the context of China-US trade negotiations. In this paper, the interaction between tariffs and the enforcement of intellectual property rights is studied within a quantitative general equilibrium framework. Results indicate that tariffs could be an effective deterrent for weak protections for intellectual property and weakening enforcement of intellectual property rights may be a strong deterrent for raising tariffs.

1. Introduction

In the wake of the 2008 financial crisis and the Great Recession, the world has seen a resurgence of protectionist policies. The Trump administration has pursued policies that aim to reduce imports into the United States and has used tariffs as a bargaining chip to protect U.S. intellectual property. In particular, the administration has sought to "punish" Chinese firms and the Chinese government for appropriation of American intellectual property through increasing tariffs in a retaliatory way. In the context of these developments, several questions naturally arise. First, to what extent are trade and intellectual property protections related? Second, how do policies governing the enforcement of intellectual property rights interact with trade policy? Third, how might we measure the effects of these policies on the welfare of citizens in each country and on the development of intellectual property?

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Although there is a large literature on both the diffusion and appropriation of technology across borders and on the causes and effects of international trade, to our knowledge, there is no unified framework in which to study the interaction between these two important forces. This paper fills the gap in the literature by merging two strands of research: the one that studies international trade and the one that studies intellectual property creation, diffusion, and appropriation. This approach allows us to address the questions above within a unified framework which allows for the exploration of the interaction between two different types of policy levers: protection of intellectual property rights and tariffs. There are a number of applications to this approach beyond the current dispute between the Trump administration and the Chinese government. The constructed framework also provides a context in which to analyze the inclusion of intellectual property rights (IPR) provisions within international trade agreements, such as NAFTA, the Trans-Pacific Partnership, and WTO agreements. The inclusion of the Trade-related Aspects of Intellectual Property Rights (TRIPS) agreement within the WTO umbrella, for example, was intended to provide additional protection of intellectual property that was diffused internationally, as well as recourse for countries that believe that their intellectual property is not being adequately protected in a foreign country.[1] We are the first, to our knowledge, to provide a framework in which the effects of these interactions can be quantified.

The main contribution is providing a unified framework in which to explore the interplay between international trade and technological innovation. The trade side builds on Ghironi and Melitz (2005), which proposes a dynamic extension of the Melitz (2003) model with monopolistic competition and heterogeneous firms. We modify their model by incorporating international transfer of technology capital, drawing heavily upon McGrattan and Prescott (2009, 2010) and, in particular on Holmes et al. (2015), which develops a model of foreign direct investment aimed at quantifying the effect of the requirement of technology capital transfer in order to gain market access, known as *quid pro quo* policies, imposed by China on international investors. Investment in technological innovation is modeled as investment in technology capital; following Holmes et al. (2015), technology capital is assumed to be non-rival intangible capital that can be used across locations. Examples of this technology capital include accumulated *know-how* obtained from investments in R&D, patents, and blueprints. Two policy levers are modeled: tariffs and enforcement of intellectual property rights. We then allow for interaction between these two policies.

In the model, entrepreneurs in a more developed country invest in a stock of non-rival technology capital. In order to start operating, new goods producing firms must rent or license this technology capital. One may think of this as firms needing blueprints in order to know how to produce. The non-rival nature of this technology capital means that the return to investing in it is increasing in the number of firms that license it.[2] Heterogeneous goods producing firms exist in both the more developed (Home) and the less developed (Foreign) country. By assumption, Foreign cannot produce its own technology capital but it may appropriate it in order to produce goods without directly paying for its use, as there is less than perfect enforcement of intellectual property rights in the foreign country. The main trade-off faced by entrepreneurs, therefore, is the desire to increase the return to their non-rival technology capital by renting it in multiple countries but knowing that renting it out in countries with weak enforcement of intellectual property rights may result in appropriation. The main trade-off faced by the agents in Foreign is that appropriating technology capital reduces the cost of production but goods made with appropriated technology capital cannot be traded internationally, so paying licensing fees gives these firms access to the international market. Most importantly, technology capital must be legally licensed first, before being subject to possible appropriation.[3] There is scope, therefore, for the two policy levers that we include to have an impact on firm decisions.

A number of experiments are conducted to explore model dynamics. First, we show that an increase in home tariffs on foreign goods reduces international trade. Exports and imports fall simultaneously and firm profits fall across the board, lowering output in both countries. However, the foreign country bears the brunt of this policy action. Tariffs directly lower demand for foreign products, resulting in depreciation of the real exchange rate in Foreign. In contrast, the imposition of tariffs is welfare improving in Home. Home consumers benefit not only from a real exchange rate appreciation that lowers the relative price of imported goods, but also from tariff revenues that are rebated back to them as a lump-sum. Most importantly, home entrepreneurs obtain more royalties when tariffs increase. The intuition is as follows. In Foreign, more expensive imported goods from Home – due to the real currency depreciation – encourages substitution away from imported goods. This action induces more firm entry in Foreign, leading to a greater technology transfer from Home and, therefore, an increase in royalties.

Then a tit-for-tat tariff escalation in which an increase in tariffs is reciprocated by an identical move by the less developed partner country is analyzed. This ultimately leads to a full-blown trade war with very high tariffs. In this case, even if Foreign ends up increasing tariffs by more than Home, retaliation serves to punish Foreign much more than it punishes Home. By sharply slashing imports, foreign consumers face a greatly reduced access to consumption goods produced by home firms in the developed country that are far more efficient. Instead, they are forced to largely rely on less-productive local producers as a result.[4]

[1] See Beshkar and Bond (2008) for details.

[2] See McGrattan and Prescott (2010) for a nice discussion of this.

[3] As an example, Siemens had a joint venture with China National Rail (CNR) that completed Chinas first high-speed rail line in 2008. The next line was built by CNR, with only a minor role for Siemens. See Holmes et al. (2015) for details.

[4] To illustrate this with a simple example, consider China's reliance on imported computers chips from the US, which makes it vulnerable in a trade war (see Financial Times December 8, 2018).

While retaliation by Foreign with tariffs maybe ineffective, Foreign can obtain different results by weakening the enforcement of intellectual property rights of home entrepreneurs within its borders. This policy move induces home entrepreneurs to license less of their technology capital to Foreign, meaning that fewer licensed firms operate in Foreign. In turn, foreign appropriators more freely seize the existing stock of home technology deployed in Foreign. This boosts the production of counterfeited goods, thus eating market share from licensed producers that are both established in Foreign and are exporting from Home. In Home, entrepreneurs will receive fewer royalties from licensed firms; in Foreign, the appropriators greatly increase their profits and their employees see their wages increase. By weakening the enforcement of intellectual capital enough, the foreign country may fully reverse the welfare results arising from an increase in home tariffs: welfare increases in Foreign and falls in Home. Put differently, *beggar-thy-neighbour* becomes *beggar-thyself* after this alternative type of retaliation.

The reverse scenario where Foreign increases its appropriation of home technology capital and Home retaliates by increasing tariffs is then explored. If Foreign appropriates technology without retaliation, it improves its welfare stance at the cost of the welfare of Home. However, in this case, Home is able to retaliate effectively with an increase in tariffs. Together, these results imply that there is scope for cooperation. It is important to note that optimal policy analysis is not conducted. However, the model environment resembles an infinitely repeated prisoners' dilemma in which the threat of an effective retaliatory grim trigger strategy in both countries supports cooperation in equilibrium.

Related Literature

To the best of our knowledge, this is the first paper to study the interaction between international trade policy and the diffusion and appropriation of intellectual property by foreign entities. On the policy front, this paper shows how retaliatory tariffs interact with changes to policies that govern the enforcement of intellectual property rights (IPR) to jointly characterize the dynamics of trade and R&D following a change to either policy. The structural approach taken here also allows for welfare analysis of alternative policy specifications.

This paper is related to several strands of research. It combines two important frameworks: Ghironi and Melitz (2005),[5] which builds a dynamic model of international trade, and Holmes et al. (2015), which models international technology flows across countries within multinational enterprises. Ghironi and Melitz (2005) is a dynamic, stochastic two-country trade model that extends the workhorse (Melitz, 2003) model by allowing for macroeconomic dynamics through the inclusion of household saving which funds costly firm creation. We build upon this framework by incorporating technology capital, which was first introduced by McGrattan and Prescott (2009) and was further developed in Holmes et al. (2015). Instead of household saving directly funding the creation of new firms as in Ghironi and Melitz (2005), here, it funds entrepreneurial investment in technology capital. As in Holmes et al. (2015), this technology capital is non-rivalrous in nature and may be appropriated if deployed to countries with weak intellectual property rights (IPR). We innovate on the set-up in Holmes et al. (2015) by allowing for technology capital to be rented to arms-length parties, as in Waddle (2018), which allows us to explore the more general case of supply chain integration, whether that integration occurs within the boundaries of a multinational firm or via supply chain agreements between arms-length parties.

This paper also contributes to a growing literature which focuses on the impact of trade policy on aggregate variables in a dynamic setting. Closely related is Akcigit et al. (2018), which builds a model with a dynamic link between trade and a firm's innovation decisions and find that in their model environment, unilaterally increasing import tariffs decreases innovation. Along these same lines, Coelli et al. (2016) and Boler et al. (2012) study the impact that and trade liberalizations have upon innovation and find that innovation and import activity are closely linked and that liberalizations encourage innovation. We add to this literature by exploring the interaction between trade policy and IPR enforcement in the context of global supply chains. Barbiero et al. (2017), Batattieri et al. (2018), Erceg et al. (2017), Farhi et al. (2014), and Linde and Pescatori (2019) are some notable examples that explore the effect of trade policy instruments on macroeconomic dynamics, though none focus on innovation and intellectual property.

Also related is the literature that explores international technology diffusion through trade, as well as spillovers to the local economy. Holmes et al. (2015) focuses on the idea that technology is transferred within the bounds of a joint venture between a multinational enterprise and a Chinese firm. This technology capital is then appropriated by Chinese firms and used outside of the joint venture, creating a transfer of that technology to local Chinese producers. Perla et al (2019) show that trade liberalization induces more rapid technology adoption. We draw upon these studies and consider a framework where expropriation is one of the explicit costs faced by the producers of technology capital if they choose to rent it to intermediate goods producers in countries with weak IPR protection. Furthermore, in the model, foreign firms can avoid trade barriers by transferring technology to foreign arms-length parties. This idea closely relates to the existing literature that studies the phenomenon of "tariff-jumping" through FDI, meaning that firms avoid tariffs by locating production in the destination market. Refer, for instance, to Blonigen et al. (2004) and references therein for details.

We also contribute to the literature that explores the impact that intellectual property protection policy has upon trade and technology transfer. Lin and Lincoln (2017), Lee and Mansfield (1996), Smith (2001), and Branstetter et al. (2006) all show that strong enforcement of IPR promotes trade and expansion of multinational production, as well as technological

[5] Alessandria and Choi (2007) present a very similar model.

innovation. Relatedly, there is a theoretical literature that focuses on the settlement of disputes between WTO members, and examines the mechanisms whereby countries may be allowed to retaliate against violation of trade agreements by weakening enforcement of IPR or vice versa. Beshkar and Bond (2008) provides a nice summary of this literature.

2. Trade and technology transfer in the data

The channels through which technology is diffused across countries have been studied in some detail. It has been shown that trade relationships are an important factor determining the extent to which technology flows across borders. The existing empirical literature shows that intellectual property is transferred between countries both within the boundaries of multinational enterprises (MNEs) and outside of them, through trade connections.

Many authors have focused on the transfer of technology between multinational parent companies and their foreign affiliates. In part, this is due to explicit technology sharing agreements, such as the one that was in place for any multinationals operating in China until the recent past. Holmes et al. (2015) discusses the implementation of this policy in China and provides evidence that, although these joint ventures do create substantial transfer of technology, this technology does not get re-exported from China. Jiang et al. (2018) also study the case of technology transfer to China within joint ventures and the impact that this has on domestic technology in China through spillovers. They, too, show that the transfer of technology is significant and that there are sizable spillovers to the economy at large as a result. Branstetter et al. (2006) look at technological transfer within MNEs more generally and show that the strength of IPR enforcement is a good predictor of the extent to which technology will be transferred from a U.S. multinational to its foreign affiliates. Again, they make a case that technology transfers between parents and affiliates are sizable, though much more so when there are stronger patent protections.

A parallel literature exists that explores the role that international trade in intermediates, capital, and embodied technology play in international technological diffusion. Acharya and Keller (2009), Caselli and Coleman (2001), and Xu and Wang (2001) explore the relationship between technological diffusion and each of the aforementioned forms of trade. They establish that trade openness and strong IPR protections encourage this diffusion and that trade is a good conduit for R&D spillovers.

We add to this empirical literature by providing suggestive evidence that, in additional to technology being diffused through ownership channels, technology transfer occurs between multinationals, which are the primary producers of new technologies in the United States,[6] and unaffiliated parties through vertically integrated supply chains between the multinationals and suppliers of intermediate goods. We examine industry-level data from the Bureau of Economic Analysis (BEA) Benchmark Surveys of US Direct Investment Abroad from 1999 and 2004. These survey report information on royalties received by parents from both their foreign affiliates and from unaffiliated parties. Royalty payments include payments for industrial products and processes, franchise fees, fees for the use of trademarks, and payments for other intangibles. Notably, the payments for industrial products and processes capture technology licensing fees and these fees account for the vast majority of the total royalty payments.[7]

Following Branstetter et al. (2006), royalty payments are used as a proxy for technological transfer. We depart from their specification by examining royalty payments received by parents from unaffiliated parties, versus their focus on intra-firm royalty payments in order to explore whether these transfers occur across countries through arms-length relationships as well.[8] They assert that multinationals are reluctant to transfer technology through non-ownership channels, a claim which they support with anecdotal evidence from Lee and Mansfield (1996). However, in the survey years analyzed here, roughly 30 to 35 percent of all royalties received by US parents are paid by unaffiliated parties, indicating that technology is, indeed, transferred through arms-length channels.[9] We focus on the royalties that are received from unaffiliated parties and examine the relationship between these royalty receipts and imports from unaffiliated parties. The data on royalties and imports from unaffiliated parties are publicly available at the industry-level in benchmark years. In order to test the impact of imports on royalty receipts, the following equation is estimated:

$$ln(Roy_{it}) = \beta_0 + \beta_1 ln(Imports_{it}) + \beta_2 Size_{it} + \gamma_i + T_t + \epsilon_{it}, \tag{1}$$

where Roy_{it} is the royalties received by parents from unaffiliated parties in industry i and year t, $Imports_{it}$ is the imports from unaffiliated parties, $Size_{it}$ is the size of the industry in year t, which we measure either by sales by parents in the industry or employment by parents, and γ_i and T_t are industry and time-fixed fixed effects, respectively. It is important to control for the industry size, as it has been established that larger industries tend to be more R&D intensive, thus increasing the size of royalty receipts in those industries. As can be seen in Table 1, controlling for industry and time fixed effects, a one percent increase in imports from unaffiliated parties is associated with roughly a 1.4 percent increase in royalties received from unaffiliated parties. If one additionally controls for the size of the industry in the United States, either using

6 Multinational Enterprises are responsible for roughly 90 percent of all research and development spending that occurs in the United States.

7 Technology licensing fees accounted for 88 percent of all royalty payments in 1989 (Branstetter et al., 2006).

8 Branstetter et al. (2006) establish that MNEs transfer technology from parent to affiliates and they do so more intensively when the affiliate is located in a country with strong IPR.

9 It is likely that the technology that is being transferred is not the “crown jewels,” but rather less advanced or less valuable technologies. The model will account for this fact.

Table 1
Royalties and trade.

Variable	(1) ln(Royalties)	(2) ln(Royalties)	(3) ln(Royalties)
ln(Unaff Imports)	1.431**	1.049*	1.054*
	(0.582)	(0.548)	(0.517)
ln(Parent Emp)		2.545*	
		(1.290)	
ln(Parent Sales)			2.559**
			(1.129)
Observations	47	47	47
R-squared	0.764	0.899	0.908

Standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

parent sales or parent employment, an increase imports from unaffiliated parties is associated with roughly a 1.05 percent increase in royalties received by the parent from unaffiliated parties. These estimates are statistically significant at the 5 and 10 percent levels, respectively.

One might be concerned that royalties received by the parent are not a good proxy for the transfer of technology. Branstetter et al. (2006) discuss why this variable does, in fact, measure the transfer of technology well. To summarize their argument, the existing tax code virtually ensures that royalty receipts are measuring payments for the transfer of technology and accurately reflect the value of this technology. We take these results as evidence that technology transfer occurs through arms-length relationships between the developers of technology capital, multinationals, and foreign entities who seek to use it, in addition to occurring through the ownership channels explored in previous studies.

This evidence combined indicates that technology is transferred by those that produce it through a number of channels. In the model that follows, technology transfer occurs through arms-length supply chain connections between the producers of technology capital (ideas) and those firms that use the technology in order to produce goods. The assumption of transfer through arms-length relationships is made primarily for analytical convenience. However it should be noted that one can think of this case as encapsulating transfers both from the multinational parent to its foreign subsidiaries, as well as transfers from the producer of the technology capital to an arms-length user, as both subsidiaries and arms-length users of technology must pay royalties to the producer of the technology capital in order to use it.[10] In the appendix, this assumption is relaxed and results are qualitatively unchanged.

3. Model

The model environment consists of two countries: Home and Foreign. They differ in their productivity, their ability to produce technology capital, and their protection of intellectual property. Home is assumed to be relatively more developed, meaning that it is more productive and it is capable of creating new technology capital. It consists of two types of representative agents: Entrepreneurs that produce technology capital and households that supply labor to produce goods and also own the goods producing firms. Furthermore, Home has perfect enforcement of intellectual property rights, meaning that intellectual property is not subject to appropriation. Foreign, on the other hand, is not able to produce technology capital and therefore only consists of a single type of representative household which supplies labor in order to produce goods. These households also own two types of goods-producing firms, which will be referred to as *licensed* and *appropriating* firms. All prospective entering licensed firms in both Home and Foreign will have to buy technology capital from home entrepreneurs in order to enter the marketplace, paying royalty fees to the entrepreneurs in exchange for the use of technology capital. This technology capital may be interpreted as the stock of patents, technological *know-how*, or brands[11] and from the entering firms' perspective these royalty payments constitute an irreversible sunk-cost investment that they incur only once.[12] Foreign is assumed to have less than perfect protection of intellectual property rights and, therefore, technology capital that is used by licensed firms in the foreign country may be subject to appropriation. *Appropriating* firms in Foreign use appropriated technology capital in order to produce goods that replicate those produced by licensed firms in both Home and Foreign, and so licensed producers in both countries may be displaced by appropriating firms. It is assumed, however, that goods that are produced by appropriating firms can only be sold within the boundaries of the foreign economy, based on evidence presented in Holmes et al. (2015). Two policy instruments are considered: tariffs and intellectual property protection and the model allows for interaction between the two, meaning that the home economy may be able to respond to changes in the enforcement of intellectual property in the foreign economy with a change in tariffs and vice versa.

[10] In a simplified setting with homogeneous producers of intermediate goods, it can easily be shown that the case where technology capital is rented by the producers of the intermediates from the producer of the technology capital is isomorphic to the case where technology capital is transferred from the multinational parent company to its foreign subsidiaries. See Waddle (2019) for a more in-depth discussion.

[11] One may think of this as firms needing blueprints in order to know how to produce.

[12] In the data, licensing fees and royalties take many forms. For simplicity, focus will be placed on agreements in which the recipient of the technology capital pays a one-time licensing fee to the creator of that technology capital for its use.

3.1. Home

3.1.1. Consumption preferences

Entrepreneurs and Households share the same preferences over a continuum, Ω, of heterogeneous consumption goods, ω: $C_t = (\int_{\omega\in\Omega_t} c_t(\omega)^{(\theta-1)/\theta} d\omega)^{\theta/(\theta-1)}$, were $\theta > 1$ is the elasticity of substitution across goods. Each firm in Home or in Foreign produces a single variety, ω, of consumption good which can be consumed domestically or exported. Firm entry and exit in Home and Foreign will determine how many varieties are available for consumption in any given period of time t: $\Omega_t \subset \Omega$. Consumption of each variety ω is denoted as $c_t(\omega)$, and its price, $p_t(\omega)$, is expressed in domestic currency.[13] The consumption-based price index, CPI, for Home is $P_t = (\int_{\omega\in\Omega_t} p_t(\omega)^{1-\theta} d\omega)^{1/(\theta-1)}$, and the resulting demand for each variety ω is $c_t(\omega) = (p_t(\omega)/P_t)^{-\theta} C_t$. Hereafter, home variables will be expressed in real terms, i.e. in units of the CPI. Aggregate consumption of the home country, denoted by C_t, is the sum of the consumption of the households, $C_{h,t}$, and of the entrepreneurs, $C_{e,t}$, and may therefore be expressed $C_t = C_{h,t} + C_{e,t}$.

3.1.2. Entrepreneurs

Entrepreneurs maximize their inter-temporal utility of consumption, $C_{e,t}$, : $\mathbb{E}_t \sum_{s=t}^{\infty} \beta^{s-t} C_{e,s}^{1-\gamma}/(1-\gamma)$, where γ is the elasticity of inter-temporal substitution. They supply labor inelastically ($L_{e,t} \equiv L_e \equiv 1$) to their own firms and therefore do not receive a wage. They accumulate technology capital, M_t, which evolves as follows:

$$M_t = X_t + (1-\delta_M) M_{t-1,} \tag{2}$$

where X_t is the investment in new technology capital and δ_M is its depreciation.

To start operating, prospective entrants in Home, $N_{E,t}$, and Foreign, $N^*_{E,t}$, need to license brands or buy patents from these technology capital entrepreneurs. Entrepreneurs' technology capital, M_t, is non-rival in nature and can be potentially rented to all entrants in Home and Foreign without being depleted. In exchange for this service, prospective home entrants pay royalties, $R_t M_{t-1}$, to entrepreneurs, where R_t is the rental rate of technology capital. A similar contract is arranged with foreign start-ups. Royalty payments constitute a sunk entry costs that new firms incur only once.[14]

Deployment of Technology Capital in Foreign

Given its non-rival nature, the *same* domestic investment in technology capital may be costlessly transferred to Foreign. However, entrepreneurs may choose to deploy less technology capital than they have available due to the presence of imperfect protection of intellectual property.[15] In order to do so, they may choose to lower the intensity of deployment of their technology capital to Foreign, by only renting a fraction q_t of their total stock of technology capital at any given time t. Entrepreneurs that choose to deploy technology capital in Foreign with an intensity q_t, will end up transferring $h(q_t) \in [0, 1]$ units of its technology capital to the appropriators in Foreign. In Holmes et al. (2015), this is due to an explicit *quid pro quo* policy, whereby multinationals which operate in Foreign are forced to transfer a fraction of their technology in order to operate in the country. Because technology is transferred through arms-length channels, this no long needs to be interpreted as a *quid pro quo* arrangement, though this set-up is isomorphic to the one with explicit *quid pro quo* arrangements.

The function $h(.)$ is weakly increasing and weakly convex in q_t:

$$h(q_t) = \Theta_t[q_t \exp(-\eta(1-q_t))]; \text{ with } \eta > 0. \tag{3}$$

This increasing functional form in square brackets follows Holmes et al. (2015) and implies that the more technology capital is transferred, the greater Foreign's appropriation of technology. Its convexity captures the idea that entrepreneurs might be willing to transfer small or less important ideas, while protecting the most important ones by only renting them in the home country. Notice that $h(.)$ will be affected by exogenous changes in policy, characterized by Θ_t, which will be described in more detail in Section 3.3. The evolution of technology capital deployed in Foreign, M^*_t, evolves as follows:

$$M^*_t = X_t + (1-\delta_M)(1-h(q_t)) M^*_{t-1}. \tag{4}$$

Note that domestic investment in technology, X_t, also serves to accumulate technology capital in Foreign. The last term accounts for capital depletion, which includes both depreciation, δ_M, and the losses suffered from the appropriation of technology capital by foreign appropriators, $h(q_t)$.

Optimality Conditions

In order to better understand the role that the non-rivalry of technology capital plays in the model, it is instructive to examine the problem being solved by entrepreneurs. Their sources of income include royalties received from entrants in both countries and lump-sum transfers of collected tariffs, $\Pi_{e,t}$, that are rebated back to them by the government. The sum of royalties paid by all $N_{E,t}$ entrants in the home country equal $R_t M_{t-1} N_{E,t}$. Given the choice of how intensively to deploy their technology capital abroad, q_t, the royalties received by entrepreneurs from foreign entrants equals $\mathbb{Q}_t R^*_t (q_t M^*_{t-1}) N^*_{E,t}$,

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13 Money is introduced solely as a convenient unit of account and plays no other role in this setting.

14 One may think of this as entrants purchasing a blueprint and paying a licensing fee for it.

15 One can think of this as entrepreneurs selling fewer blueprints to foreign producers.

where $\mathbb{Q}_t = \varepsilon_t P_t^*/P_t$ is the consumption-based real exchange rate and ε_t is the nominal exchange rate.[16] The per-period budget constraint may then be expressed as

$$C_{e,t} + X_t = R_t M_{t-1} N_{E,t} + \mathbb{Q}_t R_t^* \left(q_t M_{t-1}^*\right) N_{E,t}^* + \Pi_{e,t}. \tag{5}$$

Entrepreneurs choose consumption, $C_{e,t}$, investment, X_t, and the intensity with which to deploy their technology to Foreign, q_t, in order to maximize their utility subject to the budget constraint, Eq. (5), and the laws of motion for technology capital deployed in Home and Foreign (Eqs. (2) and (4), respectively). The solution to this maximization problem yields the following equilibrium conditions:

$$C_{e,t}^{-\gamma} = \lambda_t + \lambda_t^*, \tag{6}$$

$$\lambda_t = \beta \mathbb{E}_t \left\{ C_{e,t+1}^{-\gamma} (R_{t+1} N_{E,t+1}) + \lambda_{t+1} (1 - \delta_M) \right\}, \tag{7}$$

$$\lambda_t^* = \beta \mathbb{E}_t \left\{ C_{e,t+1}^{-\gamma} \left(\mathbb{Q}_{t+1} q_{t+1} R_{t+1}^* N_{E,t+1}^* \right) + \lambda_{t+1}^* (1 - \delta_M)(1 - h(q_{t+1})) \right\}, \tag{8}$$

$$\begin{aligned} &C_{e,t}^{-\gamma} \left(\mathbb{Q}_t M_{t-1}^* R_t^* N_{E,t}^* \right) = \lambda_t^* (1 - \delta_M) h'(q_t) M_{t-1}^*, \\ &\text{with } h'(q_t) = \Theta_t (1 + \eta q_t) \exp(-\eta(1 - q_t)), \end{aligned} \tag{9}$$

where $\lambda_t$and λ_t^* are the multipliers associated with the laws of motion for technology capital in Home and Foreign. Eqs. (7) and (8) are the Euler equations for the capital deployed in the home country and in the foreign country, respectively.

Eq. (6) shows that by sacrificing one unit of consumption today in order to increase investment, entrepreneurs increase the stock of non-rival technology capital that is available to be deployed to both Home and Foreign. The pay-off to entrepreneurs is captured by $\lambda_t + \lambda_t^*$. Recall that because this stock of technology capital is non-rival, it can be costlessly deployed in both countries at the same time in the next period. The Euler equations (Eqs. (7) and (8)) illustrate the payoffs that this extra unit of technology capital will yield: (discounted) royalty payments in $t+1$ plus the capital net of depreciation carried into the subsequent period. In particular, Eq. (8) highlights the key trade-off faced by entrepreneurs in this framework: a higher transfer q_{t+1} will increase royalties received by the entrepreneur but will decrease the stock of technology capital in the future given that agents in Foreign will appropriate some of the technology capital, represented by $1 - h(q_{t+1})$. Finally, Eq. (9) illustrates the decision rule for q_t given this inter-temporal trade-off.

3.1.3. Households in the home country

The representative households solve a problem that is similar to that of the entrepreneurs, maximizing their inter-temporal utility: $\mathbb{E}_t \sum_{s=t}^{\infty} \beta^{s-t} C_{h,s}^{1-\gamma}/(1-\gamma)$. Furthermore, they supply labor inelastically ($L_t \equiv L \equiv 1$) and receive a wage w_t. They also hold shares of a fully diversified mutual fund which consists of ownership of all domestic firms that produce in period t: $N_{D,t}$. The number of existing firms is affected by entry and exit: new entrants, $N_{E,t}$, in period t start producing (and paying dividends) in period $t+1$ and continue doing so until they are hit by an exit-inducing (bankruptcy) shock. The exit shock occurs with probability δ and affects existing incumbents and new entrants alike.[17] The resulting law of motion for the number of firms is:

$$N_{D,t} = (1 - \delta)(N_{D,t-1} + N_{E,t-1}). \tag{10}$$

In period t, the mutual fund pays the *average* dividend paid by firms, $\tilde{d}_t$, multiplied by the number of home firms that produce in period t. Therefore, households' total income from ownership of the mutual fund is equal to $\tilde{d}_t N_{D,t}$. Because the household wants a full diversified portfolio, the mutual fund administrator buys shares of all entering firms every period $N_{E,t}\tilde{\upsilon}_t$, where $\tilde{\upsilon}_t$ is the share (stock) value of the average firm. As shown later, the share value of the average entrant and existing incumbents is the same. The mutual fund administrator re-balances the portfolio each period to account for entry and exit; households repurchase their portfolio of surviving firms while shares of new firms are added to the existing portfolio and those of the exiting firms are written off. Given this, we can express the budget constraint of the representative household as:

$$N_{E,t}\tilde{\upsilon}_t + C_{h,t} = w_t L + N_{D,t}\tilde{d}_t + \Pi_{h,t}, \tag{11}$$

where $\Pi_{h,t}$ are lump-sum transfers to the household from the government, which rebate the tariffs collected on imports from Foreign. Households choose consumption, $C_{h,t}$, the number of entering firms, $N_{E,t}$, and therefore the number of operating firms in period $t+1$, $N_{D,t+1}$,[18] to maximize their utility subject to Eqs. (10) and (11). This maximization delivers the following first order conditions:

$$\lambda_{h,t} = C_{h,t}^{-\gamma}, \tag{12}$$

[16] The consumption-based price index for Foreign is defined in the next section. $\mathbb{Q}_t$ is interpreted as units of home consumption per units of foreign consumption, while ε_t is units of home currency per unit of foreign currency.

[17] This implies that a proportion δ of new entrants will never produce.

[18] Equivalently, households could choose the number of shares of the mutual fund to hold moving into the next period. See Ghironi and Melitz (2005) for details.

$$\epsilon_t = \frac{\tilde{\upsilon}_t \lambda_{h,t}}{(1-\delta)}, \tag{13}$$

$$\epsilon_t = \beta\left[\epsilon_{t+1}(1-\delta) + \lambda_{h,t+1}\tilde{d}_{t+1}\right] \tag{14}$$

where ϵ_t and $\lambda_{h,t}$ are the Lagrange multipliers on Eqs. (10) and (11), respectively.

Combining Eqs. (12) through (14) and rearranging yields the standard Euler equation for share holdings:

$$\tilde{\upsilon}_t = \beta(1-\delta)\mathbb{E}_t\left[\left(\frac{C_{h,t+1}}{C_{h,t}}\right)^{-\gamma}(\tilde{d}_{t+1} + \tilde{\upsilon}_{t+1})\right]. \tag{15}$$

Absent speculative bubbles, forward iteration of Eq. (15) yields the asset pricing equation:

$$\tilde{\upsilon}_t = \mathbb{E}_t\sum_{s=t}^{\infty}\left[\beta(1-\delta)^{s-t}\left(\frac{C_{h,s}}{C_{h,t}}\right)^{-\gamma}\tilde{d}_s\right]. \tag{16}$$

In equilibrium, the average firm value, $\tilde{\upsilon}_t$, is the present discounted value of the expected stream of dividends, where the stochastic discount factor takes into account the possibility of firm exit, δ.

3.1.4. Firms in the home country

Prior to entry, individual firms are identical and face a sunk entry cost, $f_{E,t}$, which is equal to the royalties paid to the entrepreneurs for use of technology capital: $f_{E,t} = R_t M_{t-1}$.[19] Free entry implies that entry occurs until the average firm value is equal to the sunk entry cost for each firm. Namely, the royalties paid must equal the average value of the firm: $\tilde{\upsilon}_t = f_{E,t}$. Upon entry, firms draw their firm-specific productivity level $\mathbf{z}$ from a common distribution $G(\mathbf{z})$ with support $[\mathbf{z}_{\min}, \infty)$, which remains constant thereafter. Each firm produces a distinct variety, ω. Therefore, the idiosyncratic productivity $\mathbf{z}$ may also serve as an index for the specific variety produced by the firm.

Labor is the only factor of production. Each firm produces $Z_t\mathbf{z}$ units of output per unit of labor employed, where Z_t is country-specific aggregate TFP, which is equivalent to labor productivity. Labor productivity is subject to exogenous time-varying shocks and may be expressed as $Z_t = \varepsilon_t^Z Z$. The cost of production is $w_t/(Z_t\mathbf{z})$, where w_t is the real wage, measured in units of the consumption price index, P_t. In the domestic market, firms charge a fixed markup $\theta/(\theta-1)$ over production costs: $\rho_{D,t}(\mathbf{z}) = \frac{p_{D,t}(\mathbf{z})}{P_t} = \frac{\theta}{(\theta-1)}\frac{w_t}{Z_t\mathbf{z}}$, where $\rho_{D,t}(\mathbf{z})$ is the price of variety $\mathbf{z}$ in real terms.

Exports

There are three costs to exporting. First, every exporter incurs a per-period fixed cost of exporting, $f_{X,t}$, as in Melitz (2003).[20] Because of these fixed-costs, only the most productive (high $\mathbf{z}$) firms export. Exporters incur two additional ad-valorum costs: iceberg trade costs, $\tilde{\tau} \geqslant 1$, and tariffs charged by Foreign at the dock (FOB basis), τ_t. The price of exports, $\rho_{X,t}(\mathbf{z})$, include both of these costs: $\rho_{X,t}(\mathbf{z}) = \frac{p_{X,t}(\mathbf{z})}{P_t^*} = \mathbb{Q}_t^{-1}(1+\tau_t)\tilde{\tau}\rho_{D,t}(\mathbf{z})$. Note that export prices are expressed in units of the destination country price index; here, exports from Home into Foreign are expressed in the foreign price index.

Dividends from domestic, $d_{D,t}(\mathbf{z})$, and foreign sales, $d_{X,t}(\mathbf{z})$ are therefore expressed as:

$$d_{D,t}(\mathbf{z}) = \frac{1}{\theta}[\rho_{D,t}(\mathbf{z})]^{1-\theta}C_t, \tag{17}$$

$$d_{X,t}(\mathbf{z}) = \frac{\mathbb{Q}_t}{\theta}[\rho_{X,t}(\mathbf{z})]^{1-\theta}C_t^* - f_{X,t}, \text{ if firm } \mathbf{z} \text{ exports, 0 otherwise.} \tag{18}$$

The firm's total dividends, $d_t(\mathbf{z})$, are equal to the sum of both domestic and foreign dividends: $d_t(\mathbf{z}) = d_{D,t}(\mathbf{z}) + d_{X,t}(\mathbf{z})$.

Firm Averages

We can define a cutoff level, $\mathbf{z}_{X,t}$, such that firms will export if firm productivity $\mathbf{z}$ is above $\mathbf{z}_{X,t} = \inf\{\mathbf{z} : d_{X,t}(\mathbf{z}) > \mathbf{0}\}$ from the distribution $G(\mathbf{z})$. Therefore, we can denote the exporters among the mass of producing firm as $N_{X,t} = \left[1 - G(\mathbf{z}_{X,t})\right]$. The average productivity for all producing firms, $\tilde{\mathbf{z}}_D$, and for exporters, $\tilde{\mathbf{z}}_{X,t}$, can then be written as:

$$\tilde{\mathbf{z}}_D \equiv \left[\int_{\mathbf{z}_{\min}}^{\infty} \mathbf{z}^{\theta-1} dG(\mathbf{z})\right]^{1/(\theta-1)}, \tag{19}$$

$$\tilde{\mathbf{z}}_{X,t} \equiv \left[\frac{1}{1-G(\mathbf{z}_{X,t})}\int_{\mathbf{z}_{X,t}}^{\infty} \mathbf{z}^{\theta-1} dG(\mathbf{z})\right]^{1/(\theta-1)}. \tag{20}$$

As shown in Melitz (2003), these firm averages summarize all relevant information for aggregate variables. In particular, $\tilde{p}_{D,t} \equiv p_{D,t}(\tilde{\mathbf{z}}_D)$ represents the average nominal domestic price for home firms, and $\tilde{p}_{X,t} \equiv p_{X,t}(\tilde{\mathbf{z}}_{X,t})$, the nominal price of

[19] Fixed costs are measured in units of effective labor: $f_{E,t} = f_e \frac{w_t}{Z_t}$.

[20] These costs are measured in units of effective labor: $f_{X,t} = f_X \frac{w_t}{Z_t}$.

home exports to Foreign. The home price index can thus be redefined as: $P_t = [N_{D,t}(\tilde{p}_{D,t})^{1-\theta} + N^*_{X,t}(\tilde{p}^*_{X,t})^{1-\theta}]^{1/(\theta-1)}$, where $N^*_{X,t}$ denotes foreign firms that export to Home, and $\tilde{p}^*_{X,t}$ denotes their corresponding nominal average price. Alternatively this can be expressed in real terms as: $1 \equiv N_{D,t}(\tilde{\rho}_{D,t})^{1-\theta} + N^*_{X,t}(\tilde{\rho}^*_{X,t})^{1-\theta}$. Average dividends from the domestic sales of all home producers can be expressed as $\tilde{d}_{D,t} \equiv d_{D,t}(\tilde{\mathbf{z}}_D)$, while average dividends from foreign sales of all home exporters can be denoted by $\tilde{d}_{X,t} \equiv d_{X,t}(\tilde{\mathbf{z}}_{X,t})$. Total average dividends from home producers is equal to the sum of dividends earned domestically and from exporting: $\tilde{d}_t \equiv \tilde{d}_{D,t} + [1 - G(\mathbf{z}_{X,t})]\tilde{d}_{X,t}$.

3.2. Foreign

In what follows, the foreign economy is described. To simplify the exposition, characteristics of the foreign economy that are identical to those in the home country are not included. These details have been relegated to the appendix, where the equilibrium conditions for the full model are also laid out.

3.2.1. Consumption bundles

Households have access to two different types of consumption goods: licensed products and products made using appropriated technology capital, which we will call "appropriated" or "counterfeit" as a short-hand. Foreign licensed firms are heterogeneous and pay licensing fees to start operating, just as home firms do. As a result, these firms have access to international markets and their goods may be freely traded across borders.

The consumption bundle of licensed goods for Foreign is similar to the bundle of aggregate consumption in the home country: $C^*_t = (\int_{\omega \in \Omega^*_t} c^*_t(\omega)^{(\theta-1)/\theta} d\omega)^{\theta/(\theta-1)}$.[21] The price of the foreign composite of licensed goods is: $P^*_t = (\int_{\omega \in \Omega^*_t} p^*_t(\omega)^{1-\theta} d\omega)^{1/(\theta-1)}$.[22] Notice, however, that the subset of goods available for consumption in the foreign economy may differ from the one available in the home economy ($\Omega^*_t \neq \Omega_t$).

The output of the appropriating sector in Foreign, $Y^*_{\mathbf{c},t}$ can only be consumed within its national boundaries: $C^*_{c,t} = Y^*_{\mathbf{c},t}$. Aggregate consumption, $C^*_{\mathbf{a},t}$, is the sum of licensed, C^*_t, and of appropriated, $C^*_{\mathbf{c},t}$, goods: $C^*_{\mathbf{a},t} = C^*_t + C^*_{\mathbf{c},t}$. For simplicity, it has been assumed that appropriators replicate all goods (imported and domestically produced) in the licensed basket consumed by the foreign households. As in Holmes et al. (2015), we further assume that appropriators are markedly less efficient at producing these goods than licensed producers are (details below). Under the assumption of perfect substitution, reduced production efficiency is isomorphic to the case where appropriators are as efficient as licensed producers but consumers heavily discount goods produced by appropriating firms.[23] One can think of goods made with appropriated technology capital as being counterfeit goods and, therefore, consumers may prefer the licensed good. Perfect substitution between counterfeit and licensed goods implies that the price of the latter, P^*_t, also serves as the aggregate consumer-price index. As in the case of Home, this price will serve as the numeraire in Foreign and, therefore, variables will be expressed in real terms.

3.2.2. Households in the foreign country

Every period, representative foreign households inelastically supply a labor to licensed, L^*_t, and appropriating, $L^*_{\mathbf{c},t}$, firms, which we normalize to one ($L^*_t \equiv L^*_{\mathbf{c},t} \equiv L^* \equiv 1$). Labor is assumed to be immobile across sectors in order to simplify the analysis.[24] They maximize inter-temporal utility similarly to their home counterparts: $\mathbb{E}_t \sum_{s=t}^{\infty} \beta^{s-t} (C^*_{a,s})^{1-\gamma}/(1-\gamma)$. Furthermore, foreign households own both the licensed and appropriating firms; they hold shares in a diversified mutual fund of publicly traded licensed firms and directly own appropriating firms.[25] Share holdings of the mutual funds are adjusted to account for entry and exit of licensed firms in Foreign as was described for Home. Appropriating firms are homogeneous and operate a Cobb-Douglas technology in order to produce. One important feature of the model is that foreign households have joint ownership of licensed and appropriating firms.[26] This implies that when foreign households pay royalties to home entrepreneurs, they internalize the fact that their appropriating firms will seize part of the technology capital transferred from home entrepreneurs.

Foreign households' budget constraint may be expressed as:

$$\tilde{\upsilon}^*_t N^*_{E,t} + C^*_{\mathbf{a},t} = w^*_t L^* + w^*_{\mathbf{c},t} L^*_{\mathbf{c}} + R^*_{\mathbf{c},t} M^*_{\mathbf{c},t-1} + N^*_{D,t} \tilde{d}^*_t + \Pi^*_t, \tag{21}$$

[21] Recall the assumption that all consumption at home is licensed due to full enforcement of intellectual property rights.

[22] The resulting demand for each individual good ω is $c^*_t(\omega) = (\rho^*_t(\omega))^{-\theta} C^*_t$, where prices of the individual varieties are expressed in units of the foreign currency.

[23] For instance, the scenario in which 1.2 units of a fake good delivers the same utility than 1 unit of (an otherwise identical) licensed good is equivalent to the scenario in which appropriators are 20 percent less productive than licensed ones, while consumers that values these goods equally.

[24] The assumption of segmented labor markets is relaxed and labor is permitted to be mobile across the two sectors in Appendix C.3. The main results hold in both specifications.

[25] In the appendix, the extreme assumption of foreign ownership of all foreign licensed firms is relaxed and the other extreme where home households own all foreign licensed firms is explored. The results are robust to this alternative specification.

[26] The data supports this feature. Appropriators have begun to manufacture their goods in the same factory that produces authentic goods. Yuandan goods is a term used to describe counterfeit goods that are made in the same factory as legitimate designer pieces without authorized permission to do so. The goods produced illegally using scraps and leftover materials from the genuine products and then sold on the black market.

where w_t^* and $w_{\mathbf{c},t}^*$ are the wages paid by licensed and appropriating producers, respectively, $M_{\mathbf{c},t-1}^*$ is the stock of appropriated technology possessed by appropriating firms and $R_{\mathbf{c},t}^*$ is its implicit rental rate. The remaining variables in Eq. (21) are the foreign equivalents to variables already described for the home economy.

3.2.3. Firms in the foreign country

Licensed firms in the foreign country solve a problem that is identical to that solved by their counterparts in Home. The resulting optimality conditions are identical to those described in Section 3.1.4. Appropriating firms perform two distinct activities. They appropriate the home entrepreneurs' technology for their own use and then they combine it with labor to produce output.

Appropriated Technology Capital

The law of motion for appropriated technology capital is as follows:

$$M_{\mathbf{c},t}^* = (1-\delta_M^*)M_{\mathbf{c},t-1}^* + h(q_t)M_{t-1}^*, \tag{22}$$

where M_{t-1}^* is technology capital transferred by home entrepreneurs to licensed firms in Foreign, and $h(q_t)M_{t-1}^*$ is the technology capital that is appropriated. $M_{\mathbf{c},t}^*$ is the resulting stock of appropriated technology capital, and $\delta_M^* \geq \delta_M$, is its depreciation rate.[27]

Production Appropriators combine labor $L_{\mathbf{c}}^* \equiv 1$ with the appropriated technology capital to produce output with a Cobb-Douglas technology: $Y_{\mathbf{c},t}^* = Z_t^* \tilde{\mathbf{z}}_D^* \Psi^* (M_{\mathbf{c},t-1}^*)^{\alpha} (L_c^*)^{1-\alpha}$, where α is the technology capital share and $\Psi^* < 1$ is the loss in productivity that results from appropriation. Labor productivity is defined by two factors, $Z_t^* \tilde{\mathbf{z}}_D^*$. The first of these, $Z_t^* = \varepsilon_t^{Z^*} Z^*$ is TFP – where $\varepsilon_t^{Z^*}$ accounts for an exogenous productivity innovation to all firms in Foreign. The second, $\tilde{\mathbf{z}}_D^*$ is time invariant and represents the average productivity of licensed producers: $G(\mathbf{z}^*)$ with support $[\mathbf{z}_{\min}^*, \infty)$. Firm maximization pins down the implicit rental rate for the appropriated technology, $R_{\mathbf{c},t}^*$, and the wages in the appropriating sector: $R_{\mathbf{c},t}^* = \alpha Y_{\mathbf{c},t}^* / M_{\mathbf{c},t-1}^*$, $w_{\mathbf{c},t}^* = (1-\alpha) Y_{\mathbf{c},t}^*$.

3.3. Policies and additional variables

Tariff and IPR policy

We incorporate two policy levers into the model. We are interested in the interplay between international trade and the diffusion of technology. It is important to note that there are no optimal policy choices, rather, exogenous shocks to policies. Furthermore, shocks to one policy will be permitted to impact the other.

Home tariffs levied on foreign imports, τ_t^*, are defined as $\tau_t^* = \varepsilon_t^{\tau^*} (\varepsilon_t^q)^{\phi} \tau^*$, where $\varepsilon_t^{\tau^*}$ captures exogenous innovations to these tariffs. Note that ε_t^q denotes an exogenous innovation to the enforcement of intellectual property rights in Foreign. Therefore, when $\phi > 0$, a change in IPR enforcement will impact the home country's level of tariffs. In this sense, the possibility of the home economy imposing lower (higher) tariffs if its foreign counterpart strengthens (relaxes) its protection and enforcement of intellectual property rights, ε_t^q, is permitted. Since there is no appropriation of intellectual capital in Home, foreign tariffs levied on home exports, τ_t, are completely exogenous by definition: $\tau_t = \varepsilon_t^{\tau} \tau$.

Re-consider Eq. (3)

$$h(q_t) = \Theta_t [q_t \exp(-\eta(1-q_t))]; \text{ with } \eta_t > 0,$$

and define $\Theta_t = \varepsilon_t^q (\varepsilon_t^{\tau^*})^{\phi^*}$ where, again, ε_t^q represents Foreign's IPR enforcement regime and $\varepsilon_t^{\tau^*}$ represents exogenous innovations to tariffs imposed by Home on imports from Foreign. One can then see that if $\phi^* > 0$ then an innovation to tariffs levied on foreign goods by Home will result in more appropriation. Therefore, it is possible for Foreign to relax (strengthen) its protection of IPR in response to higher (lower) tariffs imposed by Home.

Additional Variables

There is no financial integration across countries in the main model specification.[28] Lack of international lending and borrowing implies that the following balanced-trade condition must hold:

$$\frac{1}{(1+\tau_t)} \mathbb{Q}_t N_{X,t} (\tilde{\rho}_{X,t})^{1-\theta} C_t^* = \frac{1}{(1+\tau_t^*)} N_{X,t}^* \left(\tilde{\rho}_{X,t}^*\right)^{1-\theta} \left(C_{h,t} + C_{e,t}\right). \tag{23}$$

Specifically, the value of home exports must equal the value of foreign exports, with only licensed goods being traded internationally. Output is computed with the income-based approach and is equal to the following in the home country:

$$y_t = w_t L + N_{D,t} \tilde{d}_{D,t} + R_t M_{t-1} N_{E,t} + \mathbb{Q}_t q_t R_t^* M_{t-1}^* N_{E,t}^*. \tag{24}$$

The equation differs slightly for Foreign, as income sources differ across the two countries. Foreign output can be written as

$$y_t^* = w_t^* L^* + w_{\mathbf{c},t}^* L_{\mathbf{c}}^* + N_{D,t}^* \tilde{d}_t^* + R_{\mathbf{c},t}^* M_{\mathbf{c},t-1}^*. \tag{25}$$

[27] Consistent with the evidence, appropriated technology is allowed to depreciate at a faster rate. For instance, if appropriators encounter a problem they cannot rely on the technical support provided by the original developers. Due to lack of data availability, in the model parameterization we assume that $\delta_M^* = \delta_M$.

[28] In the appendix, this assumption is also relaxed and results are largely unchanged.

All tariff revenues are rebated in a lump-sum manner to the households in both countries: $\Pi_{h,t} = (\tau_t^*/(1+\tau_t^*))N_{X,t}^*(\tilde{\rho}_{X,t}^*)^{1-\theta}C_{h,t}$, $\Pi_t^* = (\tau_t/(1+\tau_t))N_{X,t}(\tilde{\rho}_{X,t})^{1-\theta}C_t^*$, as well as to entrepreneurs in the home country: $\Pi_{e,t} = (\tau_t^*/(1+\tau_t^*))N_{X,t}^*(\tilde{\rho}_{X,t}^*)^{1-\theta}C_{e,t}$.

In what follows, the welfare implications of different policy regimes will be analyzed. Welfare for each agent in the economy will be measured as the discounted utility from the stream of consumption from period t onward: $\mathbb{W}_{i,t} = \mathbb{E}_t\sum_{s=t}^{\infty}\beta^{s-t}C_{i,s}^{1-\gamma}/(1-\gamma)$, for $i=\{h,e,h^*\}$. The CES specification of preferences implies that price indexes can be decomposed into average prices and product variety: $P_t = \tilde{P}_t(N_{D,t}+N_{X,t}^*)^{1/(1-\theta)}$, where $\tilde{P}_t$ is the average nominal price of all the varieties sold in Home, and $(N_{D,t}+N_{X,t}^*)^{1/(1-\theta)}$ captures the variety of products. An analogous expression for holds for Foreign. $\tilde{P}_t$ is closer to the empirical measures used by statistical agencies. Therefore, a theoretical counterpart to the empirical exchange rate can be defined as $\tilde{\mathbb{Q}}_t = \varepsilon_t\tilde{P}_t^*/\tilde{P}_t$. For practical purposes, we will focus on this variable in the model simulations.

4. Model parameterization

The distribution of firm productivity draws is Pareto with lower bound $\mathbf{z}_{\min}$ and shape parameter $k > \theta - 1 : G(\mathbf{z}) = 1-(\mathbf{z}_{\min}/\mathbf{z})^k$, where k characterizes the dispersion of the draws. Average productivities $\tilde{\mathbf{z}}_D$ and $\tilde{\mathbf{z}}_{X,t}$ are defined as $\tilde{\mathbf{z}}_D = \nu\mathbf{z}_{\min}$ and $\tilde{\mathbf{z}}_{X,t} = \nu\mathbf{z}_{X,t}$, where $\nu \equiv \{k/[k-(\theta-1)]\}^{1/(\theta-1)}$. The foreign economy has an identical distribution. As in Ghironi and Melitz (2005), θ is set to 2.3 which is the same value in Bernard et al (2003). In this last paper, the estimates for the standard deviation of the log of U.S. plant sales is 1.67. In the model, this standard deviation is $1/(k-\theta-1)$, which implies that $k=3.4$. Foreign is assumed to be less productive (i.e. less developed) and, without loss of generality, $\mathbf{z}_{\min}$ is normalized to 1 and $\mathbf{z}_{\min}^*$ is set to 0.2. This implies that in the initial stationary equilibrium, the per capita output ratio for Home and Foreign is 3.09. This coincides with the current per capita output ratio for U.S. and China, measured in purchasing power parity terms. Tariffs imposed on Home, τ_t, and foreign exports, τ_t^* are 5.9% and 2.9%, respectively. This coincides with the mean effective bilateral tariffs that China and the U.S. impose on one another for the period (2002–2017). The sample period is chosen to include only the years after China's most favoured nation status became permanent (December 2001). The size of the firm exit shock ($\delta = 0.025$) matches the annual 10% job destruction observed in the U.S. data.

Each period is one quarter. Therefore, β is set to 0.99 and $\gamma = 2$, which are the standard values in the literature. The iceberg transportation cost, $\tilde{\tau}$, is set to 1.68 and is chosen to match the bilateral U.S./China trade cost estimates from ESCAP-World Bank Trade Cost Database for 2010. We normalize f_e to 1 and set the ratio of the fixed cost of entry to the fixed cost of exporting, f_e/f_X, to match the steady-state share of expenditure of domestic goods in Ghironi and Melitz (2005). This share is 0.73 and in the model implies that exporters are about 83.3% more productive than non-exporters. In the baseline calibration, the elasticity of retaliation in response to intellectual property (trade) policy innovations, $\phi(\phi^*)$, is set to zero and later allowed to vary in the policy experiments.

The remaining four parameters match the estimates in Holmes et al. (2015). The quarterly depreciation rate for the stock of technology capital, δ_M, is 0.20, while its associated income share, α, is 0.07. The productivity loss that occurs when technology capital is appropriated, Ψ^*, is set to 0.9, which implies that wages in the licensed sector are 78.9% higher that in the appropriating one. Finally, the parameter that pins down the convexity of the technology transfer is set to $\eta = 10$.[29]

Unless explicitly stated parameter values for Home and Foreign are symmetric. This symmetry reflects limitations of firm-level data for the Chinese economy. At the same time, this approach eases the comparison in the cross-country transitional dynamics described below.

5. Model dynamics

The model response to several different policy regimes and economic shocks is now examined.

5.1. An increase in tariffs on foreign goods

To begin, it is assumed that the interaction between shocks to the enforcement of intellectual property rights and shocks to tariffs levied on foreign goods at Home is zero ($\phi, \phi^* = 0$). Here, we wish to explore the impact of an exogenous increase in tariffs on imports to Home from Foreign when there is no scope for retaliation in foreign policy. The economy is shocked with a modest shock: a unilateral exogenous 1% permanent increase in tariffs applied by Home on goods imported from Foreign, increasing the tariff rate from 2.9% to 3.9%.[30] Transitional dynamics are depicted in Fig. 1 as percentage deviations from the original stationary equilibrium, where blue solid lines represent home variables, and red cross-hatched lines depict foreign variables.

As standard trade theory would predict, tariffs induce a significant decrease in imports, and given the balanced trade assumption, an equivalent decrease in exports. As a result, the number of exporting firms decreases and consumers in both

[29] This high value for η implies that entrepreneurs are able to effectively protect their "crown jewel" intellectual property, while lower values imply that these more important ideas are difficult to protect. In the appendix, the model's sensitivity to this parameter choice is explored and qualitative results are unchanged, though lower values of η imply lower royalties and smaller technological transfers.

[30] This is a permanent innovation that persists for an indefinite number of periods.

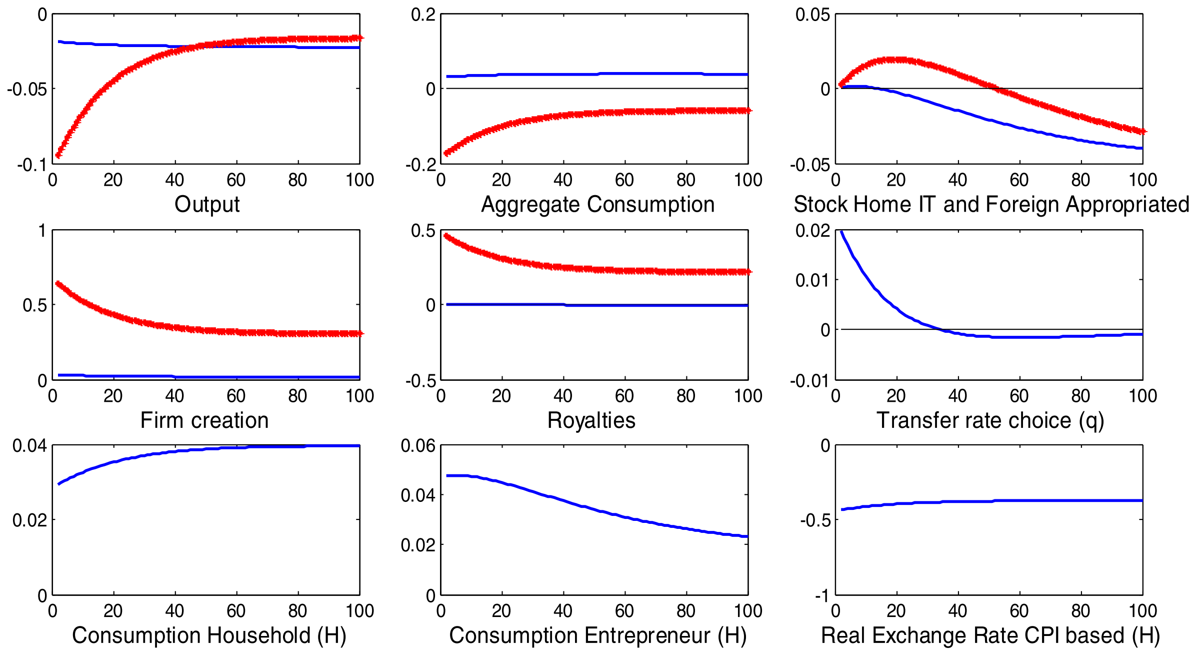

Fig. 1. Increase in Home Tariffs on Imported Foreign Goods.
Note: Model transitional dynamics following an immediate permanent 1% increase in tariffs (expressed as % deviations from the original stationary equilibrium). The blue (thin) line home variables and the red (thick) line with markers depicts foreign variables. Time periods are quarters. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

countries consume a bundle of goods with an increased proportion of domestic varieties. This manifests as an increase in domestic firm entry. Furthermore, the increase in tariffs targeting foreign goods and the resulting decrease in the demand for these products lowers their equilibrium price level, as well as foreign wages. Cheaper foreign goods translate into a real exchange rate appreciation (depreciation) for Home (Foreign) (i.e. $\tilde{\mathbb{Q}}_t$ decreases) which, in turn, means that the foreign country has a competitive edge,[31] thereby inducing relatively more firm creation in the foreign economy than in the home economy.

All else equal, the increase in firm entry in both countries implies more total royalty receipts for home entrepreneurs that supply technology capital necessary for firm creation.[32] Notice, however, that the investment in new technology capital declines slightly, thereby reducing the total stock of technology capital over time. Even though there is now more firm entry, meaning that $N_{E,t}$ increases, the rental rate for technology capital, R_t, is significantly lower in the new stationary equilibrium. This is because increased tariffs lead to a decline in profits for exporting firms, which are the most productive firms in both countries. A decline in profitability for the most productive firms necessarily implies decreased expected profits for prospective new firms, lowering the expected benefit of entry and thereby generating lower rental rates for technology capital. This decrease in the rental rate, in turn, reduces investment in new technology. Entrepreneurs optimally choose to increase their transfer rate (q_t) to the foreign economy where firm entry is relatively more robust. This is an attempt to increase the overall returns to their stock of technology capital. Over time, increased tariffs lead to an increase in the stock of appropriated technology overseas, though eventually this stock falls slightly as the investment in technology capital diminishes.

The output (income) impact of the increase in tariffs is negative for both countries, as it lowers the number of varieties available to consumers, forces reallocation of production towards less productive firms, and lowers investment in new technology capital, or innovation. Not surprisingly, the decline in income is more pervasive in Foreign, where tariffs directly impact the profitability of the most productive firms (exporters) and, as a result, the equilibrium wages. In Home, the decline in output and aggregate income is more moderate. Two things explain this. First, total royalty payments received by entrepreneurs increase as a result of more firm entry in both countries. Second, higher tariffs result in increased lump-sum transfers to home households and entrepreneurs. Relatively more of these transfers are channeled to domestic demand–given the costly trade assumption in this Melitz framework—ultimately benefiting home firms relatively more. In sum, the transfers partially offset the loss of competitiveness arising from the real exchange rate appreciation in Home.

[31] Real exchange rate appreciations following an increase in tariffs is noted in the literature, e.g., Farhi et al. (2014).

[32] Total royalty receipts from Home equal $N_{E,t}R_tM_{t-1}$ while royalty receipts from Foreign equal $N^*_{E,t}R^*_tq_tM^*_{t-1}$. Royalties are expressed in the currency of the country from which they originate.

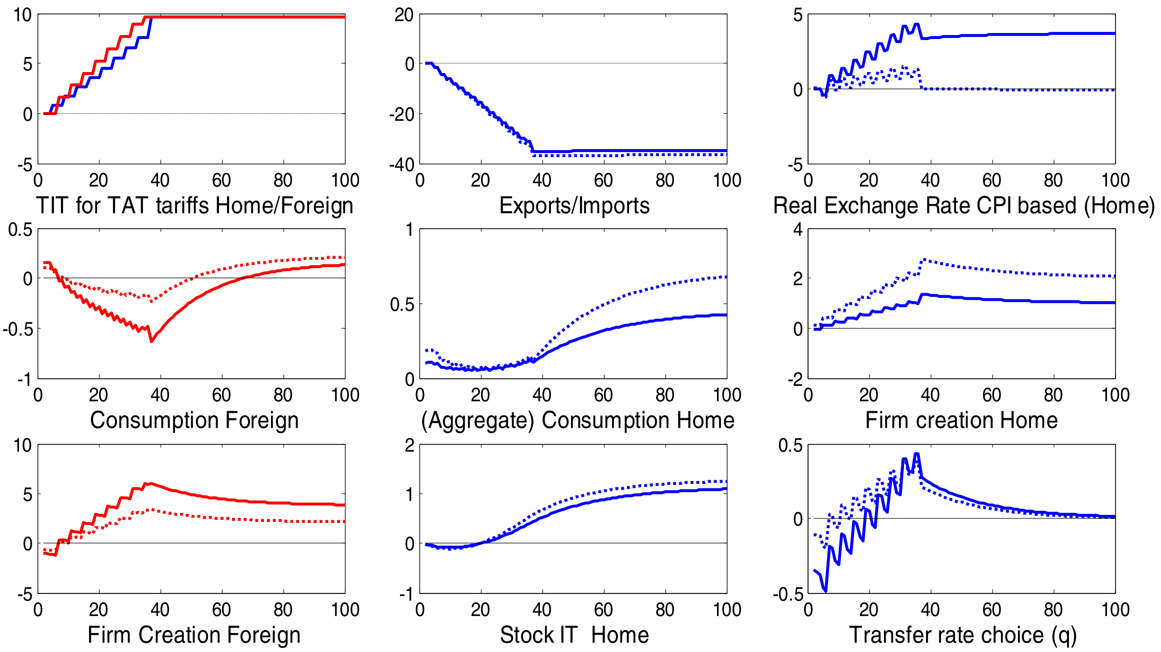

Fig. 2. Tit-for-Tat Trade War Scenario.
Note: Model transitional dynamics in response to a tit-for-tat tariff escalation in which each country matches the tariff imposed by the other until they converge to the level depicted in the first panel (expressed as % deviations from the original stationary equilibrium). In this first panel, (dark) blue indicates Home tariffs on imported goods from Foreign, and the (light) red line the opposite. In the rest of the panels, the solid line depicts the baseline model scenario, while the dotted line considers the case in which the foreign economy is as productive as the home economy. Time periods are quarters. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Most relevant for this discussion are the welfare effects of this policy move, measured as discounted consumption flows. In Foreign, the sizable decrease in household income and consumption is partly the by-product of tariffs levied on their licensed firms. Instead, in Home, rebated tariffs are more than enough to compensate for the decline in aggregate income. Indeed, an increase in tariffs is welfare improving for Home as it leads to a slight increase in consumption and welfare for both its households and entrepreneurs. However, recall that, although tariffs are not negative for the home economy in terms of consumption, they do serve to reduce innovation in the form of reduced investment in technology capital.[33]

Tit-for-tat Trade War

Now, a tit-for-tat escalation in tariffs which results in a trade war is examined. The purpose of this exercise is two-fold. First, we would like to explore what happens if Home is also subject to new tariffs, manifesting as a bilateral increase in tariffs. Second, the impact of a much larger increase in tariffs is analyzed. Therefore, in this experiment, the model economy is shocked with a series of alternating 1% increases in tariffs in Home and in Foreign, ending in a final increase in gross tariffs of 10% for both countries. Fig. 2 depicts this tit-for-tat escalation in two different scenarios, with solid lines denoting the baseline model in which Foreign is substantially less productive than Home and dotted lines depicting the case where the two countries are equally productive. Note that there is no uncertainty in this deterministic framework meaning that all agents have perfect foresight.[34]

In the first panel of Fig. 2, the evolution of gross tariffs ($1+\tau_t$ in red and $1+\tau_t^*$ in blue) is graphed to show the escalation of the trade war. The remaining panels illustrate the model's transitional dynamics in response to these policy shocks. In the initial parameterization, tariffs are significantly higher in Foreign (5.9%) than in Home (2.9%).

The trade war scenario highlights an important result. Even though the exchange rate appreciates in Foreign because its tariff base is higher, consumption in that country declines significantly in this conflict. By slashing imports from Home on a massive scale, foreign consumers face substantially reduced access to consumption goods from their trade partner which is five times more productive and are forced to substitute them for goods from local producers which are much less

[33] Tariffs are usually subject to a political and administrative delays (See for instance, Batattieri et al. (2018)). To explore how outcomes differ if there is a delay in implementation after announcement, in the appendix, we also conduct an experiment in which the 1% increase in tariffs is announced 10 quarters before it is implemented. Results are similar to the case with immediate implementation.

[34] It would be interesting to consider a possibility of uncertainty over future tariff increases; however, the current framework is not set up to analyze policy uncertainty.

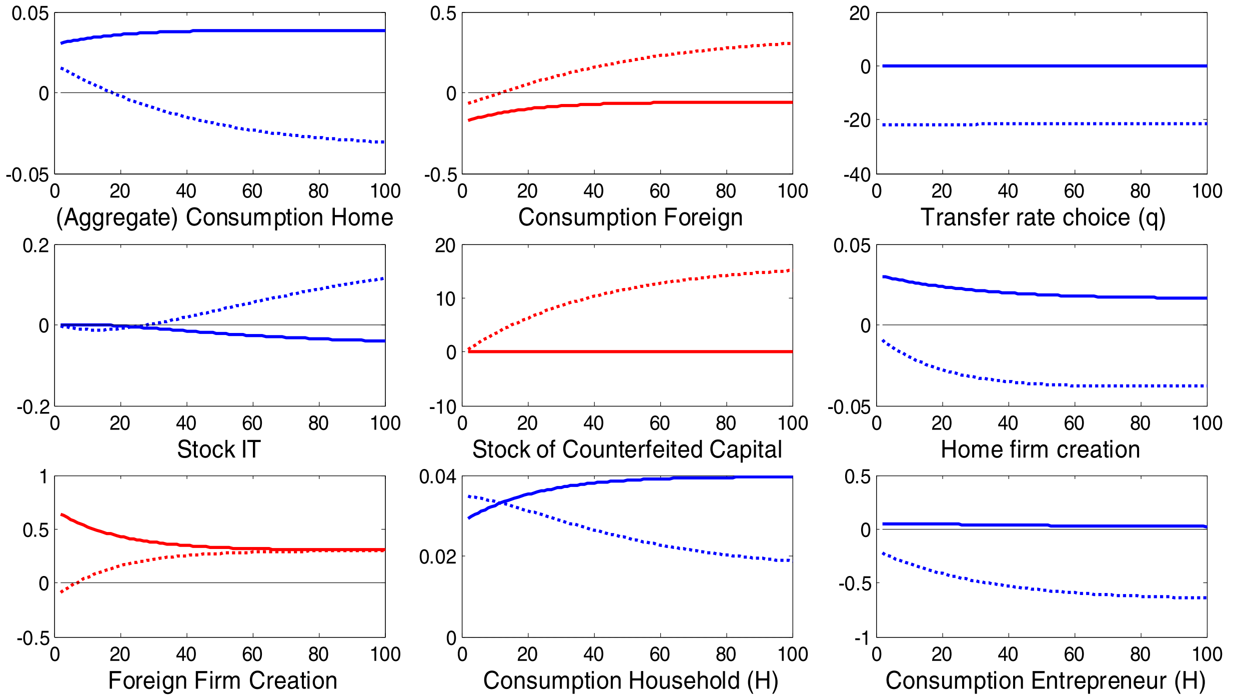

Fig. 3. An Increase in Home Tariffs with and without Foreign retaliation.
Note: The solid line displays an increase of Home Tariffs on imported goods from Foreign. The dotted line reflects the same scenario, which in this case is retaliated by Foreign with an increase on the appropriation rate of Home's Technology Capital. Expressed as % deviations from the original stationary equilibrium. Time periods are quarters.

productive.[35] Meanwhile, in the home country, the effects of a drop in imports can be partially offset by the steady entry of relatively more productive domestic firms over time.

Furthermore, the alternative specification in which the two countries are equally productive (depicted by the dotted lines) highlights that a key component of the consumption losses for Foreign is the reallocation toward less productive firms that occurs as a result of increased tariffs. Notice that when heterogeneous licensed firms draw from the same productivity distribution in both countries, consumption losses in Foreign are substantially less severe than in the baseline, where foreign licensed firms draw from a productivity distribution that is only 20% as productive as the home distribution. This is specifically because, in the baseline scenario, the trade war results in substantial efficiency losses for Foreign, whereas in the alternative specification, productivity losses are significantly dampened. As in any Meltiz-style model, an increase in tariffs results in efficiency losses in both scenarios, as the consumption of goods produced by very productive exporters are replaced by the consumption of domestic varieties.

In combination with our baseline results, the results from this scenario indicate that an increase in tariffs by Home begets a *beggar-thy-neighbor* scenario, improving its welfare at the cost of Foreign's well-being. If Foreign follows suit by retaliating and escalating the conflict in a tit-for-tat fashion, it only serves to decrease the welfare of its own agents. Therefore, this retaliation strategy is not a good one for the foreign country to consider. In the experiments that follow, other forms of retaliation are considered.

5.2. Retaliation

In Fig. 3, the baseline depicting a 1% unilateral increase in home tariffs on foreign imports is denoted by the solid lines. We now deviate from that baseline by allowing Foreign to respond to an exogenous increase in tariffs by increasing the appropriation of intellectual property. Recall Eq. (3):

$$h(q_t) = \Theta_t[q_t \exp(-\eta(1-q_t))]; \text{ with } \eta_t > 0,$$

where $\Theta_t = \varepsilon_t^q (\varepsilon_t^{\tau^*})^{\phi^*}$. In the baseline, ϕ^* was set to zero, meaning that a shock to tariffs on foreign imports into the home country would not result in any change in the appropriation of home technology capital. In this experiment, instead, the elasticity of appropriation, ϕ^*, is set to 5[36] and again the economy is shocked with a 1% increase in tariffs on foreign

[35] Recall that in the parameterization, $\mathbf{z}_{\min}$ is normalized to 1 and $\mathbf{z}^*_{\min}$ is set to 0.2.
[36] The appendix includes sensitivity analysis to this parameter choice. Qualitative results are unchanged under alternative parameter specifications.

imports into Home, $\varepsilon_t^{\tau^*}$. The dotted lines illustrate the response in both economies to this scenario. Again, recall that there is no choice for the social planner in either country; the shock to tariffs is exogenous and the response in Foreign is guided by parameter choices. However, the model allows for an endogenous change in the *level* of appropriation in response to the tariff shock.

Entrepreneurs react to the change in the enforcement of intellectual property by sharply reducing the transfer of technology capital, q_t. Nevertheless, the fall in the transfer rate does not completely offset the increase in appropriation and, therefore, there is a sizable increase in the stock of appropriated technology capital. A robust non-tradable appropriating sector displaces licensed producers in Foreign as the stock of appropriated technology capital increases. Furthermore, firm entry in Home declines substantially because foreign consumers substitute toward the appropriating sector and away from imported goods from Home. Therefore, the expected profitability of firm entry at Home declines and, with it, home firm creation.[37]

Perhaps surprisingly, the stock of home technology capital *increases* in this environment. However, it should be noted that this increase occurs through a reduction in the transfer of technology across borders, not through increased innovation. Entrepreneurs drop their transfer rate substantially following the policy change that increases appropriation. This, in turn, means that the depreciation rate for this capital essentially falls.

The most notable result from this experiment it that the foreign policy-maker can fully revert the losses arising from the original imposition of tariffs by its Home counterpart, turning them into substantial consumption gains for foreign households by responding to tariffs with increased appropriation. Moreover, by taking this action, Foreign converts the slight consumption gains for home entrepreneurs in the baseline scenario to sizable losses, as royalties drop significantly when appropriation rises. Gains for the home households that were originally obtained from higher tariffs also fall with this retaliation, as home exporters now lose market share to appropriators. To better see this, the first panel of Fig. 3 aggregates the consumption of home households and entrepreneurs, showing an absolute decline following the retaliation. In summary, the imposition of tariffs increases home consumption at the expense of the foreign consumer. However, this foreign retaliation in the form of increased appropriation fully reverses the original gains for the home economy. In other words, the *beggar-thy-neighbor* intent of Home becomes a *beggar-thyself* in the face of this retaliation.

Home Tariff Retaliation in Response to Technology Capital Appropriation

Fig. 4 considers the case where Home retaliates to an increase in appropriation with an increase in tariffs. This is an interesting experiment given the recent increase in U.S. tariffs against China which are meant, in part, to punish perceived appropriation of U.S. intellectual property by Chinese firms. Furthermore this experiment speaks to the idea of cross-retaliation, as is permitted by the WTO in certain instances. First an exogenous increase in the appropriation of technology capital by Foreign is considered, and then, a retaliation by Home in the form of an increase in tariffs is allowed. Mechanically, this means that the model economy is shocked by a doubling of ε_t^q (increasing ε_t^q by 100%) in Eq. (3), which translates into a reduction in the rate of technology transfer of roughly 10%.

Recall that the tariffs imposed by Home on imports from Foreign are defined by $\tau_t^* = \varepsilon_t^{\tau^*}(\varepsilon_t^q)^\phi \tau^*$. In this experiment, ϕ is set to 1, so that the *level* of these tariffs may endogenously respond to a change in appropriation.[38] Here, the solid lines in Fig. 4 illustrate the case where the appropriation parameter is shocked and there is no response in home policy ($\phi = 0$); the dotted lines, instead, illustrate the model dynamics in response to the scenario with Home retaliation to this appropriation shock.

The intuition for the transitional dynamics arising from an exogenous increase in appropriation of technology capital with no retaliation is similar to the intuition described in the scenario where appropriation is increased in retaliation to increased tariffs. In this scenario, we see that there is a reduction in the rate of technology transfer and an increase in appropriated technology capital. The home country is worse off after the unilateral appropriation of technology by Foreign: entrepreneurs receive fewer royalties, as licensed producers in both countries are displaced by foreign appropriators. Households are worse off too, as foreign consumers substitute away from home imports and towards goods produced by appropriators.

Nonetheless, Home can effectively retaliate against Foreign with a sizable increase in tariffs. As described in more detail in the description of the baseline scenario, this policy action decreases the profits and wages paid by licensed foreign firms, while making imports from Home relatively more expensive due to the exchange rate depreciation. In turn, home households benefit from the extra income received from rebated tariffs and from cheaper imports, while entrepreneurs see an increase in royalties as the decline in trade promotes export substitution and firm entry.

When the home country increases tariffs, it is made better off than in the case with no retaliation, at the cost of decreasing foreign welfare. It is not able to fully reverse the negative impact of appropriation on the entrepreneur; however, increased tariffs are able to slightly improve welfare for entrepreneurs. This is because tariffs encourage home firm creation, as home consumers substitute towards domestic varieties. Therefore, entrepreneurs are able to reap benefits from increased royalty payments from a larger number of entering firms.

Once again, the general conclusions from this retaliation by Home are the same as the case in which Foreign retaliates. If Foreign increases its appropriation technology capital, it engages in a *beggar-thy-neighbor* policy: foreign consumption

[37] Entry in the foreign economy only recovers in the long run, when the growth of the appropriating sector results in a substantial increase in income in Foreign. Therefore, total demand for consumption increases and with it, the demand for goods produced in the licensed sector. This also explains why eventually the stock of technology capital increases.

[38] Again, tariffs are not chosen by a social planner, but instead are exogenously given.

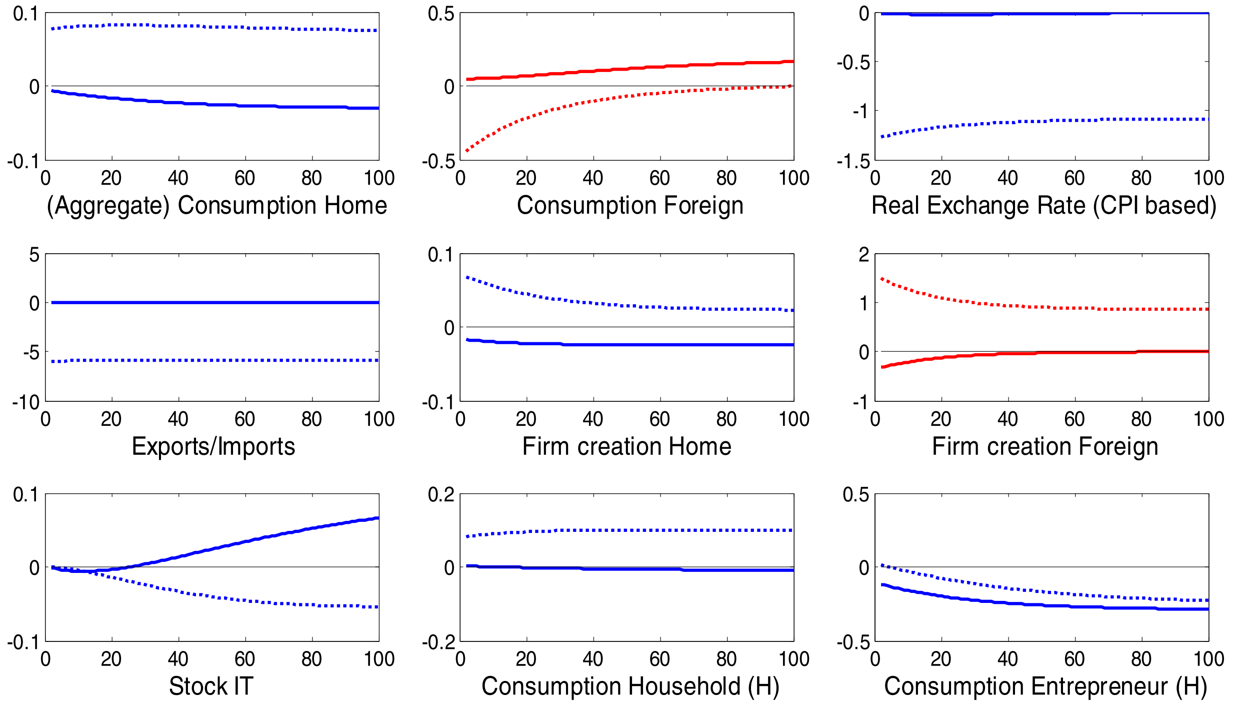

Fig. 4. An Increase in Technology Capital Appropriation with and without Home retaliation.
Note: The solid line displays an increase in foreign appropriation of Home's Technology Capital. The dotted reflects the same scenario, which in this case is retaliated with an increase of Home tariffs on imported goods from Foreign. Expressed as % deviations from the original stationary equilibrium. Time periods are quarters.

increases and aggregate consumption in the home economy falls. These results are reversed when Home implements a tariff retaliation, rendering the initial act of appropriation as a *beggar-thyself* scenario.

To conclude, both countries potentially have a trigger strategy that can punish the other if it deviates from the original stationary equilibrium. This would potentially make the original equilibrium stable and the threat of tariffs or intellectual property appropriation not credible.

5.3. An increase in total factor productivity

We now study the case where the country-level productivity, TFP, increases in each country. Fig. 5 shows model dynamics in response to an increase in Home (blue solid) and Foreign (red dotted) productivity. All agents benefit in both of these scenarios. Quantitatively, agents benefit significantly more when the productivity increase occurs in their own country, both in terms of output and consumption.

The presence of more productive firms incentivizes firm entry and leads to a higher rental rate for technology capital in equilibrium. In the standard trade model with no technology capital, an increase in productivity at Home will result in net destruction of firms in the foreign economy (i.e. the exit rate is higher than the entry rate). That is, as more productive home firms enter, less competitive foreign firms are displaced. This is not the case in this model. As entrepreneurs accumulate more technology capital, they transfer more of it to foreign firms. Therefore, the implicit rental rate in the foreign economy drops which, in turn, incentivizes more entry despite lower relative productivity.

If the TFP shock occurs in Foreign, the reaction of the entrepreneurs is more muted. Notably, the technology transfer rate to Foreign, q_t, barely changes after this shock. The convexity of the function governing the extent of appropriation, $h(.)$, implies the degree of appropriation increases exponentially with the rate of transfer. Ultimately, this prevents the entrepreneurs from transferring too much technology capital despite the productivity gains abroad.[39] One will also note that following a TFP shock to Foreign, exports from Foreign rise, as do royalties paid to home entrepreneurs. The increase in these both variables at the same time is consistent with what was found in the empirical portion of the paper.

[39] The empirically-consistent hump-shaped response of the real exchange rate to technology shocks mimics the model dynamics in Ghironi and Melitz (2005). The number of producers increases in the new stationary equilibrium. This leads to an increase in the demand for inelastic labor, which ultimately leads to an appreciation of the labor costs and real exchange rate appreciation. However, in the short-run –before firm entry takes place– the increase in productivity results in excess supply of effective labor units that lowers the labor cost of production, resulting in a real exchange rate depreciation.

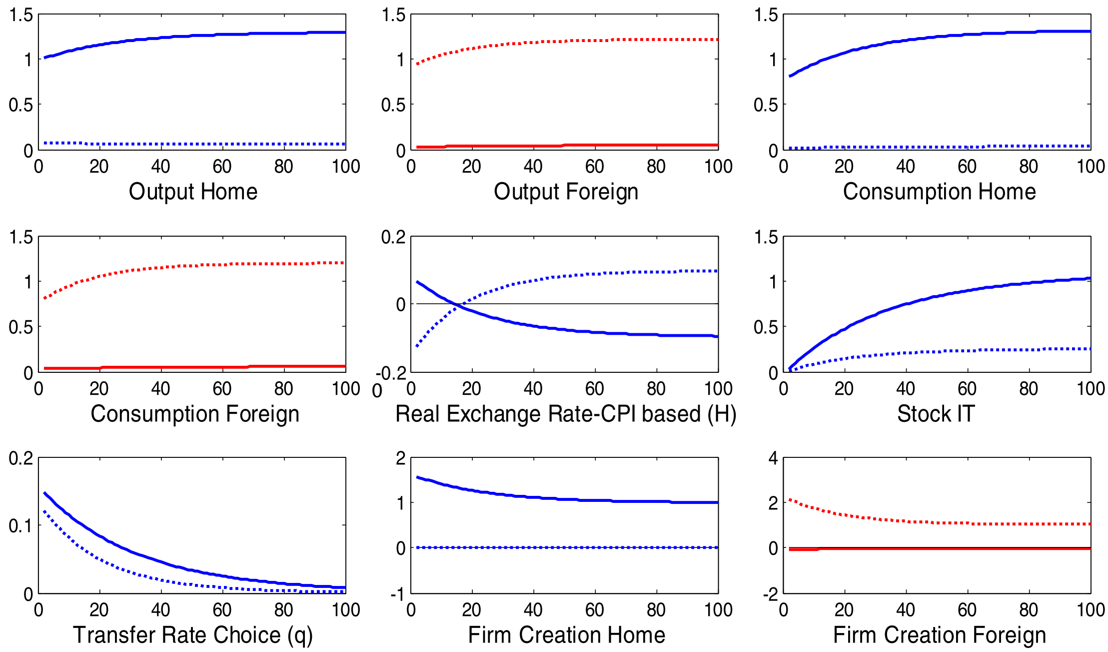

Fig. 5. Productivity increase in Home and Foreign.
Note: Model transitional dynamics following a permanent 1% increase in productivity in Home (solid) and Foreign (dotted). Expressed as a % deviations from the original stationary equilibrium. Time periods are quarters.

In the online appendix, additional experiments are considered, including a delayed implementation of the unilateral increase in tariffs, a case where tariffs fall *and* IP protections improves (meant to mimic China's accession to the WTO), and scenarios which relax some of the assumptions made above. In particular, we allow for Home ownership of foreign licensed firms (meant to mimic multinational production), international financial integration, and labor that is fully mobile across the licensed and unlicensed sector in Foreign.

6. Conclusion

This paper provides a unified framework to analyze the interaction between international trade and the development and diffusion of technology capital. Two important policy levers – tariffs and enforcement of intellectual property – have been included in the framework to allow analysis of how retaliation in the face of negative policies from a foreign counterpart impact both the home and the foreign country. To our knowledge, this is the first paper to provide a unified framework in which to study the interplay between trade and the appropriation of intellectual property by foreign entities. It therefore provides an important bridge for policy-makers who wish to study the current interactions between China and the United States. The main finding is that the possibility of retaliation can effectively deter each country from engaging in a policy that, if unanswered, will negatively impact the other. In this sense, there is scope for cooperation between the two countries.

A number of abstractions are made in the analysis. First, the model only includes two countries. There are a number of ways including an additional country in the model would enrich the analysis. For example, it would be interesting to consider a case where goods produced using appropriated technology could be sold to a third country, thus increasing the cost of appropriation to the home country. Similarly, one could imagine a scenario in which firms would have an incentive to move production to the third country in response to an increase in tariffs on goods made in one country but not on goods made in the third.[40]

Another limitation of our two-country set-up is that technology capital is only created in the more developed country. While in the data it is true that the vast majority of new technologies are developed in advanced economies, a three country set-up would allow researchers to explore the interplay between two economies which develop new technologies and how the less developed country might substitute trade with a second advanced economy, for example the European Union, if the first, for example the United States, were to impose higher tariffs. This substitution of trade partners might have important implications for both the more and the less advanced countries.

Most importantly, optimal policy design is not explored in the analysis. This is an important and interesting avenue for future research. The framework presented here treats policies as primarily exogenous, as they are subject to exogenous

[40] There is an existing literature on tariff-jumping, but this literature does not include an analysis of technology capital and its appropriation.

shocks. Even when one policy is allowed to endogenously respond to the other, there is a policy rule that governs this response. While this reduced form analysis is useful for understanding the impact that these policies have on agents in the economy, it would also be useful to expand upon the analysis to see whether these policies mimic those that are optimal from the stand point of a social planner. A fruitful line of future research will build upon the framework presented here in order to analyze the game theoretical interactions of policy makers.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jmoneco.2019.10.013.

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