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Technological and Economic Decoupling in the Cyber Era

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Abstract

The COVID-19 pandemic has accelerated the shift toward digital services. Meanwhile, the race for technological and economic leadership has heated up, with risks of decoupling that could set back trade and growth and hinder the recovery from the worst global recession since the Great Depression. This paper studies the conditions under which a country may seek to erect barriers—banning imports or exports of cyber technologies—and in effect promote decoupling or deglobalization. A well-known result is that banning imports may be optimal in monopolistic sectors, such as the digital sector. The novel result of this paper is that banning exports can also be optimal, and in some cases superior, as it prevents technological diffusion to a challenger that may eventually become the global supplier, capturing monopoly rents and posing cybersecurity risks. However, export or import bans would come at a deleterious cost to the global economy. The paper concludes that fostering international cooperation, including in the cyber domain, could be key to avoiding technological and economic decoupling and securing better livelihoods.

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I. Introduction

In December 2017, the U.S. administration signaled a shift in foreign policy, from viewing China as a potential "responsible stakeholder" in the international community to calling it a "strategic competitor" (U.S. National Security Strategy 2017). It viewed competition along technological, security, and economic dimensions. Also, in a break from the past, it linked these three issues, which had previously been treated as distinct. Shortly thereafter, it raised tariffs on Chinese imports. This was followed by a tit-for-tat escalation, sanctions on specific firms involved in developing certain new technologies, and warnings to trading partners against purchasing technologies from these firms. The outbreak of COVID-19 accelerated the shift toward digital services and further ratcheted up global tensions, as major economic powers started tightening restrictions on technological and financial sector access and eyeing a decoupling of their supply chains. In late 2020, China made technological self-reliance a priority of its 14th five-year plan.[2] Fundamental uncertainty remains as to the end game.

From a standard macroeconomic perspective, it has been difficult to make much sense of this ongoing trade war. Some of the economic issues cited as justification, such as bilateral trade balances and charges of currency manipulation, find little resonance among most economists. Other issues such as access to China's markets and protection of intellectual property are ones that the Chinese authorities also have acknowledged they wish to make progress on, although differences of views remain as to how quickly and effectively they could move and what role external pressure can play. In any event, resorting to escalating tariffs is likely to harm, not benefit, the communities that have been left behind in recent decades. If anything, the uncertainty engendered by the conflict is damaging growth and investment, not just in the United States and China but globally (IMF 2019b). This is even more so in the COVID-19 environment, where concerns about the pace of recovery and economic scarring abound.

It is therefore to the evolving technological and security landscape that one must turn to make sense broadly of the damaging trade war. As the world has become increasingly digitalized and networked, new growth engines have taken shape. These include newer services built on data, such as next generation (5G) networks, the internet of things, artificial intelligence, machine learning, distributed ledger technology, and quantum computing. Leadership in such emerging technologies bestows outsized profits, global market shares, and the ability to set standards.

With a winner-take-most dynamic—rooted in economies of scale and scope—global technological leadership is highly prized. Such a dynamic has in fact been shown to be at work in the past two decades. As discussed in IMF (2019a), a small fraction of highly productive and innovative firms has exacted rising market power, measured by growing price markups over marginal costs. This result is broad based across sectors and economies.

But the race for technological leadership is complicated by the fact that digitalization and connectivity bring new security threats. Although the networked economy allows one to

[2] Communiqué of the Fifth Plenary Session of the 19th Central Committee of the Communist Party of China, October 2020.

reach seamlessly across the world to collect information and make decisions, it also can allow thieves, saboteurs, and spies to reach back to steal, manipulate, or destroy. Borders and intellectual property were not designed into the foundations of the internet.

Cyber threats are of increasing and material concern. Surveys of risk managers consistently show cyberattacks to be one of the biggest threats to business. The World Economic Forum (2019), for instance, cited cyberattacks, alongside climate shocks, as the highest impact and most likely threat. In mid-2018, the US Director of National Intelligence, Dan Coats, said in relation to cyberattacks, "The warning lights are blinking red again. We are at a critical point. Today, the digital infrastructure that serves this country is literally under attack." In this regard, the U.S. government has been issuing warnings, for instance, against purchasing 5G equipment from some foreign manufacturers for fear of opening backdoors into networks. Concerns and warnings about cyberattacks have increased during COVID-19, amid increased remote working as well as generalized fears about the pandemic.

Viewed from these lenses, the interconnections of the cyber age can simultaneously be engines of economic growth and channels of security risks. They can hence blur heretofore traditional distinctions between economic and security issues, and incentivize the use of economic policy tools for broader security or geopolitical gains (Farrell and Newman 2019). Macroeconomists have not had to consider security matters, except where conflict and crime dominate. Rather, for the most part, they have taken as given the institutional underpinnings for safeguarding property rights and treated military matters as a fundamentally distinct field. In cyber space, however, there are no such distinctions yet, no effective domestic norms or public institutions for enforcing security such as e-police or e-justice system (Moore et al. 2009), and no international mechanisms for de-escalation and maintaining peace (e.g., Balsillie 2018, Tett, 2019, and Rodrik 2020).

Against this backdrop, several questions arise. How might one analytically frame the pursuit of technological leadership, adoption of new technologies, and simultaneously heightened security risks? What are the implications for trade and growth, not only between those jostling for leadership but also for the rest of the world? While New Trade Theory suggests that there might be a case for technological laggards to impose trade barriers, when if ever might it make sense for technological leaders to do so? Should this apply only to those challenging the leader or globally to non-competitors as well? What should the latter do? Are there winners and losers? What might be the elements of a globally optimal outcome?

This paper proposes a simple macroeconomic framework to provide initial responses. It develops a dynamic general-equilibrium model of international trade where two countries compete for global markets of digital goods, and their governments can set trade and industrial policies strategically. The model incorporates monopoly power in the digital sector, technological growth and diffusion across countries, cybersecurity vulnerabilities, and the possibility of regime changes in the patterns of trade.[3]

[3] In our model, exporters can switch to become importers (and vice versa), there is technological leapfrogging, and there are incentives for decoupling. These features differentiate the paper from Mandelman and Waddle (2020), who also study the interaction between technology diffusion and optimal trade policy but keep fixed the roles of importer and exporter.

While the international trade literature has long shown how increasing returns to scale in production can make it optimal for an *importer* to stop trade (Krugman and Obstfeld, 2003, Chapter 11), the novel result here is that it may also be optimal for an *exporter* to do so. What we are witnessing are bans on imports and exports, and this is what we term technological and economic decoupling.

In the model, the production of a "digital" input is characterized by a natural monopoly. A country may find it optimal to ban *imports* of the digital input to repatriate *monopoly rents*. If the country has a profitable domestic producer, it can be beneficial to ban foreign competition and avoid monopoly rents accruing to foreign shareholders, even if domestic production is less efficient. In addition, sourcing the digital input from abroad introduces a *security vulnerability* as it exposes the importer to cross-border cyberattacks. This is modelled as a trade friction that increases the cost of sourcing the digital good from a foreign monopolist.[4]

However, with international *technology diffusion*, which itself could be a proxy for security vulnerabilities as it could be linked not just to benign learning by using and transfers but to coercion and theft of intellectual property, a country may also find it optimal to ban *exports* of the digital input. Exporting it to a technologically inferior country increases the latter's ability to eventually become the global producer, capturing monopoly rents.

The expected productivity growth rate in the digital input plays a key role in determining whether the technology leader may impose an export or an import ban on a potential challenger. If the challenger is expected to eventually surpass the technology of the leader, the leader may be keen to delay the inevitable moment of leapfrogging by banning exports and limiting diffusion of knowhow. If, however, growth rates at the technological frontier are expected to be the same, import bans would suffice, as the leader could limit the scale economies needed for the challenger to become more competitive and, hence, preserve its monopoly rents in third markets.

As the two competing countries can impose trade restrictions on each other, the possibility of game-theoretic strategic interaction appears. Indeed, import bans are shown to lead to strategic interaction, as the best response of each country depends on the other's response. For example, if banning imports from a rival allows a country to capture the global market, it is possible that the rival retaliates in kind, leading to an inefficient outcome with a domestic producer in each country. In a repeated game, this could lead to even more complex interactions, where credible threats could potentially sustain free trade policies. On the other hand, exports bans do not lead to strategic interaction between the two countries, as they would only be imposed by a technological leader. Hence, they may be harder to deter with retaliatory trade policies even in a repeated setup.

Trade bans can be optimal for each country individually, given the monopoly rents and cyber security vulnerabilities. But they effectively promote technological and economic

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[4] While in practice cyberattacks can also originate domestically, this assumption reflects that opening up to foreign digital inputs increases the risk.

decoupling, slowing technological diffusion, and thus are deleterious for global welfare (see also IMF, 2018). As highlighted in the seminal work of Romer (1986, 1990), the sharing of ideas and technology has characteristics of a global public good. Technological diffusion, while protecting intellectual property rights, is advisable and a common market practice that can foster economic convergence and global growth. Improving outcomes will require at a minimum international cooperation to reduce cyber security vulnerabilities. But as this will still leave open sizable monopoly rents, there will still be incentives to ban exports or imports. Two other dimensions of international cooperation are considered: strengthening protection of intellectual property and facilitating broad cross-border ownership of suppliers to align incentives. These may not be easy as the role of the state and relations between the state and domestic or international firms are re-thought in this new cyber age.

The policy results hinge on the existence of relevant monopoly rents in one sector. This could explain why, in the past, large tradeable sectors such as car manufacturing, which exhibit lower monopolistic rents than the digital sector (IMF, 2019a), did not beget the same degree of trade conflict. Note also that the assumption that the monopolistic sector is an input to all sectors is not crucial. The main results would carry over to an extended set-up with multiple sectors, if in at least one sector suppliers enjoy significant rents. In that case, it would be a matter of political calculation whether imposing trade restrictions in that sector is worth risking broader trade partnerships. On the other hand, conflict in the monopolistic sector (e.g., digital) could spread to other sectors, leading to a cascading decoupling of supply chains. Similarly, a multi-sector model could allow for different leaders in different sectors (e.g., China in 5G). Finally, while in the model rents of digital suppliers reflect exclusively market power, they could be interpreted more broadly as including the political and military benefits of global dominance.

The paper is organized as follows. The next section presents the analytical framework to evaluate these issues. The third section provides illustrative simulations to show when a technological leader or a challenger may wish to use trade policy to its advantage. The fourth section discusses the key results and policy implications, while a final section concludes.

II. A Two-Country Model

This section develops a model of two countries, with a final good and a "digital" good or service. The final good is produced competitively, traded freely, and consumed in both countries. The digital good has natural monopoly properties and serves as an input into the production of the final good.

Technology in the production of the digital good may diffuse from the leader to the laggard country. Diffusion occurs gradually through learning by using when this good is internationally traded. But it has also been alleged that diffusion could be accelerated through theft of intellectual property.[5] Perceived theft of intellectual property is one dimension along which security concerns arise. A second is that use of a foreign-provided digital good increases the risk to disruptive cyberattacks, which could hinder production.

[5] The annual cost of intellectual theft for the US is estimated at 1-3 percent of GDP (IP Commission, 2017).

The problem posed is to understand the conditions under which it might be optimal for a government of either country to restrict imports or exports of the digital good, or to subsidize domestic suppliers.

A. Setup

There are two countries, $i = \{a, b\}$, each with constant population (and labor supply) L_i. Time is infinite and discrete.

Of interest are the technologies, the incentives for seeking global technological leadership, and matters of security. Hence, the demand side is posed parsimoniously.

Consumers

The representative consumer in country i derives utility by consuming the final good:

$$U_{i,t}\left(\{c_{i,s}\}_{s=t}^{\infty}\right) = \sum_{s=t}^{\infty}\left(\ln(c_{i,s})\right)\beta^{(s-t)},$$

where $c_{i,s}$ denotes country i's consumption of the final good in period s, and $\beta \in (0,1)$ is the intertemporal discount factor.

There are no savings. Hence, consumption $c_{i,t}$ is equal to income $C_{i,t}$. The final good is taken as the numeraire.

Final Good Producers

Final goods are produced in perfect competition by price-taking firms. The production function for the final good of country i is:

$$y_{i,t} = {l_{i,t}}^{1-\alpha}(B + {n_{i,t}}^{\alpha}),$$

where $l_{i,t}$ is the labor input, and $\alpha \in (0,1)$ with $(1-\alpha)$ denoting the share of labor income.[6] The digital good, $n_{i,t}$, is used as an input into the final good production in country i. The formulation with $B > 0$ allows for final good production to occur even when the digital good is absent. Modeling digital goods as an input follows Jones and Tonetti (2020), who provide micro-foundations for a similar specification in the context of data. The formulation also follows Varian (2017) in allowing for decreasing returns to scale in the use of the digital good. Note that, for simplicity, capital is not modeled, but the formulation is akin to the standard production function with capital as an input.

Final good producers maximize profits:

$$\pi_{i,t}^{f} = \max_{n_{i,t}, l_{i,t}} y_{i,t}(n_{i,t}, l_{i,t}) - p_{n,t}^{i} n_{i,t} - w_{i,t} l_{i,t}.$$

[6] The labor input could also be modeled with an exponent equal to one. The assumption here ensures that final good producers do not operate with negative profits.

where w is the wage and p_n the price of the digital good.

Digital Good Producers

Production of the digital good in country *i* entails a fixed cost *K* (incurred every period) and a marginal cost $\frac{\mathbf{1}}{\boldsymbol{A_{i,t}}}$, both in terms of the final good.[7] The denominator $\boldsymbol{A_{i,t}}$ indicates the technological level in each country. In this model, technological growth therefore takes the form of declining marginal costs in digital good production.

A producer in country *i* may supply to either country. If two digital good producers try to sell to the same country, they compete on prices. Producers choose prices after observing the entry decisions of other producers, i.e., after fixed costs are paid.

Digital goods are susceptible to attacks or security lapses. While attacks may originate from a domestic or foreign source, we focus here only on the latter for analytic simplicity and to bring to the fore the cross-border dimension of the problem. This includes the fear that countries are more vulnerable if they rely on foreign-provided digital goods or services or, alternatively, that bringing cyber thieves to justice is even more difficult when the purported crime is of a cross-border nature. Specifically, a fraction $\rho \in [0,1]$ of the foreign-provided digital good is lost in a cyberattack each period. Equivalently, each unit of the digital good supplied to a foreign country requires producing $\frac{1}{1-\rho}$ units. This formalizes the assumption that the attack makes foreign provision of the digital good less effective.

A producer from country i that has paid the fixed cost maximizes profits of supplying to country $j \in \{a, b\}$:

$$\pi_{i,t}^{j} = \max_{n_{i,t}^{j}} \left(p_{n,t}^{j}\left(n_{i,t}^{j}\right) - \frac{1}{\left(1 - \rho * I(i \neq j)\right) A_{i,t}} \right) n_{i,t}^{j}$$

where $n_{i,t}^{j}$ is the quantity of the digital good supplied to country j by a producer from country i and $I(\cdot)$ is the indicator function.

If a producer from country i pays the fixed cost, total net profits are equal to:

$$\Pi_{i,t} = \pi_{i,t}^{i} + \pi_{i,t}^{-i} - K + \tau_{i,t} \,,$$

where $\tau_{i,t} \geq 0$ is a subsidy to the fixed cost, conditional on the firm being active.[8] Appendix III analyzes the implications of subsidies proportional to production in the domestic and foreign markets respectively.

[7] The assumption of a single digital good is not crucial. It would be equivalent to assume that a continuum M of symmetric monopolistic competitors produce differentiated digital goods, which are aggregated as follows: $y_{i,t} = \int_0^{M_i} \left({l_{m,t}}^{1-\alpha} (B + {n_{m,t}}^{\alpha}) \right) dm.$

[8] Subsidies could also be more broadly interpreted as including non-fiscal transfers of value, such as laws weakening consumers' property rights over their personal data, that can support the production of digital goods.

Technology

One of the countries is at the technological frontier A_F (so, $A_{i,t} = A_{F,t}$), which grows exogenously at rate $g_i \geq 1$.

The country below the frontier bridges a fraction of the distance to the frontier every period it is connected to the global network, i.e., if it is trading in the digital good. In other words, there is diffusion through learning by using. Following Acemoglu (2009, Chapter 18.2):

$$A_{i,t} = A_{i,t-1} * g_i + \sigma_i * \left(A_{F,t-1} - A_{i,t-1}\right) * I\left(n_{-i,t}^{i} + n_{i,t}^{-i} > 0\right), \quad (1)$$

where $\sigma_i \geq 0$ parametrizes the speed of technology diffusion. Note if the laggard country has higher fundamental technological growth g_i it can overtake the leader and become the frontier country.

Digital producers are assumed not to internalize the effect of their actions on the aggregate technology level.[9]

Security

One way of modeling cyber security issues is, as discussed above, allowing for cyberattacks ($\rho > 0$) that cut off a fraction of foreign-provided digital goods.[10]

Cyber security may be further modeled through the diffusion parameter, σ. Transfer or theft of intellectual property implies a faster closure of the technology gap and, hence, a higher σ.

Government

The government's role is to conduct trade and industrial policy. In any period, a country can unilaterally ban imports from the other country (denoted $b_{i,t}^{i} = 1$) or its own exports (denoted $b_{i,t}^{-i} = 1$). Subsidies are financed with lump-sum taxes on consumers: $T_{t,i} = \tau_{i,t}$ if a domestic producer is active.[11] The government chooses its policies to maximize domestic utility $U_{i,t}$.

Consumer's budget constraint

The representative consumer's income is equal to wages plus the profits of domestic final and digital good firms minus lump-sum taxes:

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[9] This could be micro-founded assuming a continuum of monopolistic network producers producing differentiated inputs, as shown in footnote 4.

[10] Alternatively, ρ can be interpreted as a generic cost to trade in digital goods.

[11] The assumption of lump-sum taxation is for simplicity. Funding the subsidy with distortionary taxation would increase its cost in terms of aggregate utility.

$$C_{i,t} = w_{i,t} l_{i,t} + \pi^f_{i,t} + \Pi_{i,t} - T_{i,t}.$$ [12]

B. Static Equilibrium

Definition

The static equilibrium is defined by quantities $\{y_{i,t}, l_{i,t}, n_{i,t}, n^i_{i,t}, n^{-i}_{i,t}, c_{i,t}\}$ and prices $\{w_{i,t}, p^i_{n,t}\}$ for each country $i = \{a, b\}$ such that, given technologies $A_{i,t}$ and government decisions $\{b^i_{i,t}, b^{-i}_{i,t}, \tau_{i,t}\}$, firms maximize profits, and the final good, digital good and labor markets clear. The optimal government decisions will be characterized as part of the dynamic equilibrium.

Solution

Final good producers

Since final good producers are price takers, input prices for labor w and digital goods p_n equal their marginal products in revenues:

$$w_{i,t} = (1-\alpha){l_{i,t}}^{-\alpha}(B + {n_{i,t}}^{\alpha}),$$
$$p^i_{n,t} = \alpha {l_{i,t}}^{1-\alpha} {n_{i,t}}^{\alpha-1}.$$

It will be useful to define the demand function for digital goods from the equation above:

$$n(p, l) = \left(\frac{\alpha}{p}\right)^{\frac{1}{1-\alpha}} l\,.$$

Plugging in the first order conditions into the definition of profits yields:

$$\pi^f_{i,t} = \alpha {l_{i,t}}^{1-\alpha} B.$$

Digital good producers

The first order condition for the digital good producer implies that if a producer is active in market j, its production is equal to:

$$n^j_{i,t} = \left(\left(1 - \rho * I(i \neq j)\right)\alpha^2 A_{i,t}\right)^{\frac{1}{1-\alpha}} l_{j,t}.$$

A digital good producer from country *i* produces *only if* (a) its total net profits are positive: $\Pi_{i,t} \geq 0$, and (b) no foreign producer can profitably enter in any of the markets where the producer from country *i* is selling.

Before characterizing condition (b), a few considerations are needed. First, at most one firm will sell to a given market in any given period. With positive fixed costs, as prices are bid down to marginal cost, one of the two competitors will eventually incur losses, which means

[12] Final good producers, even if they are perfect competitors, have positive profits in equilibrium if $B > 0$.

its entry is not credible. Hence, only the firm with the lowest potential price can survive. Thus, for a given country, the digital good can be either not supplied, supplied by a local monopolist, or supplied by a global monopolist. Formally, it is always the case that $n_{i,t}^{-i}\, n_{-i,t}^{i} = 0$ and $n_{i,t}^{i}\, n_{-i,t}^{i} = 0$. Second, if a producer is profitable in its domestic market, it is also profitable as a global producer, as the fixed cost is already incurred.

Condition (b) requires the following, depending on the international pattern of production:

b.1) If country i is to be a global producer, the potential domestic producer in country $-i$ must be deterred from entry in that market. This happens if the potential domestic producer $-i$ makes negative profits when the global producer is selling at its minimum possible price $\tilde{p}_{n,t}^{-i}$:

$$\left(\tilde{p}_{n,t}^{-i} - \frac{1}{A_{-i,t}}\right) n\left(\tilde{p}_{n,t}^{-i}, l_{-i,t}\right) - K + \tau_{-i,t} \leq 0. \quad (3)$$

The minimum price for the global producer $\tilde{p}_{n,t}^{-i}$ is either its marginal cost in market $-i$ or its break-even price, whichever is higher:[13]

$$\tilde{p}_{n,t}^{-i} = \max\left\{\frac{1}{(1-\rho)A_{i,t}}, \hat{p}_{n,t}^{-i}\right\},$$

where the break-even price $\hat{p}_{n,t}^{-i}$ is defined as the price where the global producer's profits are zero:

$$\pi_{i,t}^{i} + \left(\hat{p}_{n,t}^{-i} - \frac{1}{(1-\rho)A_{i,t}}\right) n\left(\hat{p}_{n,t}^{-i}, l_{-i,t}\right) - K + \tau_{i,t} = 0. \quad (2)$$

Note the cybersecurity cost $\rho > 0$ introduces an advantage for the domestic producer, which enjoys lower marginal costs in the domestic market for any level of technology.

b.2) If both countries have potentially profitable global producers and neither of them can be challenged by a domestic producer, then the one with higher potential expected profits $\Pi_{i,t}$ as a global producer prevails.[14]

b.3) If no global producer is sustainable, both countries produce domestically, provided they generate positive profits.

Obviously, condition (b) is binding only if no government bans trade in digital goods: $b_{i,t}^{j} = 0$ for any $i, j \in \{a, b\}$.

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[13] Prices below marginal cost are a non-credible threat, as the global producer would increase its profits by not delivering to the foreign market.

[14] This is an equilibrium selection mechanism. With $\rho = 0$, it is equivalent to selecting the producer that can make the lowest credible bid in a hypothetical price war. The case $\rho > 0$ is more complicated, as it implies producers from different countries can set different minimum prices in a given market, which could lead to equilibrium multiplicity. One way to interpret the proposed selection mechanism is assuming that the firm with the highest potential profits can buy out the other firm.

Market clearing

Market clearing must hold in digital goods:

$$n_{i,t} = \sum_{j=\{a,b\}} n_{j,t}^{i},$$

labor:

$$l_{i,t} = L_i,$$

and final goods:

$$\sum_{i=\{a,b\}} \left(y_{i,t} - \frac{1}{A_{i,t}} \left(\sum_{j=\{a,b\}} \frac{n_{i,t}^{j}}{1-(i \neq j)\rho} \right) - KI\left(\sum_{j=\{a,b\}} n_{i,t}^{j} > 0\right) \right) = \sum_{i=\{a,b\}} c_{i,t}.$$

That is, global final good production minus any incurred marginal and fixed costs must equal global consumption.

Given a pattern for trade in final goods, all equations can be solved analytically except for (2), which requires a numerical solution.

C. Dynamic equilibrium

Definition

A dynamic equilibrium is defined as a sequence of static equilibria over time such that, in each period t, governments choose $b_{i,t}^{j}$ and $\tau_{i,t}$ for $i, j = \{a, b\}$ to maximize lifetime utility $U_{i,t}$, given initial technology levels $A_{i,0}$ and the law of motion for technology in equation (1).

Characterization

The only dynamic choice variables are the policy tools: import bans, export bans and subsidies. This section discusses the optimal policy choices from the perspective of an individual country. It first considers each policy tool at a time and then compares them. Appendix I characterizes the first best equilibrium from a global perspective.

Note that the dynamic equilibrium only converges to a balanced growth path when time tends to infinity, given the presence of $B > 0$ and $K > 0$. Hence, intertemporal optimization must be solved numerically. The following provides a characterization of the main forces driving optimal policy choices.

Import bans

A country may find it optimal to ban imports of the digital good to repatriate monopoly rents. If the country has a profitable domestic producer, it can be beneficial to ban foreign competition and avoid rents accruing to foreign shareholders, even if domestic production would be less efficient than perfect competition.[15] In addition, sourcing the digital good from abroad exposes the country to cyberattacks $\rho > 0$. These are akin to a trade friction that is not fully absorbed in the price set by the foreign monopolist supplier, and so increases the relative cost of imports.

The decision to ban imports involves a forward-looking component because it stops technology diffusion, and so may affect the future consumption path, even for the technological leader. Aside from the technology diffusion channel, the problem is static.

The static game between two countries that are able to set import bans on each other can take the forms represented in Table 1, depending on parameters and the stock of technology in each country. The payoffs shown in the table assume, without loss of generality, that country a is the global producer under free trade.[16] They further assume that, for both countries, welfare from domestic production is higher than from importing if the domestic producer has positive profits. This latter assumption is for ease of illustration and may not hold when technology flows are taken into account, as will be seen in Section III.

If country b does not ban imports, country a is the sole producer (by assumption); in Table 1, the payoff for consumers and producers of country a is denoted A+b for supplying to its domestic and foreign markets while the payoff to consumers in country b is b (the notation is described in the notes of Table 1). The differing equilibria arise, therefore, depending on whether countries a and b are at the point where they can produce domestically under bans on imports of their digital goods.

There are potentially five types of static Nash equilibria. In type 1), country b bans imports to avoid paying monopoly rents, and both countries end up producing domestically. In type 2), country b bans imports as this allows it to be the sole global producer. In type 3), either global producer is feasible, so there exist two equilibria where either country prevails.[17] In type 4), both countries impose bans, as they both prefer autarky to importing—a full-blown trade war. In type 5), country b is not feasible as a global producer and importing is preferable to not using digital goods at all—the free trade outcome.

[15] Krugman, Obstfeld and Melitz (2018) discuss how first-mover advantage could lead to goods being inefficiently imported at a higher price than the one that would prevail if those goods were produced locally. In our model, there is no first-mover advantage, as fixed costs are incurred every period. It is possible that fixed costs deter entry from a domestic supplier with a lower marginal cost than the foreign producer, which has already paid the fixed cost to produce in its own country. However, even in that case, domestic production would not be efficient as it would require duplicating the fixed cost. What makes it optimal for a country to ban imports here are monopoly rents.

[16] If there is no global producer under free trade, import bans are irrelevant.

[17] This "coordination game" case could be prevented with a tit-for-tat strategy where countries threatened each other to mirror the import ban if one is ever imposed, although making good on such threat would have a utility cost. If such threat was credible, country a would be the global producer in equilibrium.

Table 1. Import ban with two countries (*a* and *b*): types of games and equilibria.

1) Defensive ban

a / b	no ban	ban
no ban	A+b b	A B
ban	A+b b	A B

2) Offensive ban

a / b	no ban	ban
no ban	A+b b	a a+B
ban	A+b b	0 B

3) Coordination game

a / b	no ban	ban
no ban	A+b b	a a+B
ban	A+b b	0 0

4) Full trade war

a / b	no ban	ban
no ban	A+b b	a a+B
ban	A+b b	A B

5) Free trade

a / b	no ban	ban
no ban	A+b b	A 0
ban	A+b b	A 0

Notes: Country *a*'s actions are displayed vertical and country *b*'s horizontally. Payoffs reflect the markets each country is supplying, with capital letters reflecting domestic production and small letters reflecting markets with foreign supply. For simplicity, payoffs for the supplier and consumer in a given market are represented as being the same (equal to a and b for country *a* and *b*'s markets respectively). Without loss of generality, country *a* is assumed to be the global producer under free trade. The table contains all possible combinations of payoffs. Circles denote Nash equilibria in pure strategies for each combination.

Export bans

The international trade literature has long shown that increasing returns to scale in production can make it optimal for a country to restrict *imports* (Krugman and Obstfeld, 2003, Chapter 11). The novel result in this model is that banning *exports* may also be optimal for a technological leader once technology diffusion is considered.

The decision to ban exports is forward looking. Exporting the digital good to a technologically inferior country increases the latter's ability to eventually become the global producer. Conditional on a trade pattern for the digital good (i.e., a distribution of countries supplying and importing), technological growth in country $-i$ always benefits country i, as it reduces import prices. But at the point where country $-i$ can switch from no production to production, country i's utility may decrease, as it may lose monopoly rents going forward and face increased security vulnerabilities (i.e., it becomes exposed to $\rho > 0$). Hence, while banning exports entails a reduction in current consumption because export profits vanish, it can increase consumption in the medium run by preventing or delaying the rival's entry as a global producer. In the long run though, once the trade pattern has stabilized, diffusion is never detrimental to any country. Therefore, the net impact of an export ban on utility depends on multiple factors, including the intertemporal discount rate β and the rate of technology diffusion σ.

The decision to ban exports is unconditional on the other country's trade policies and depends only on the capacity of the challenger to threaten the technological leader's pole position. This is because (1) only a technological leader would ever find it optimal to ban exports, and (2) banning exports becomes inconsequential if the other country bans imports, and vice versa. Hence, unlike import bans, export bans do not lead to strategic interaction in the game theoretic sense.[18] Importantly, this makes them harder to defuse based purely on trade policies, as tit-for-tat strategies are not effective against unilateral bans. It means that, in these circumstances, the technological leader's actions could be viewed as disruptive to global free trade while the challenger could be viewed as an upholder of global free trade. It also means that a broader set of policy instruments beyond trade would need to be considered, such as ownership of foreign producers and reducing risks or costs associated with cybersecurity, which are explained further below.

A narrower result—applicable only in a two-country set-up—is that banning exports is only optimal if banning imports is not possible.[19] Otherwise, it is preferable for a technological leader to keep exporting until its rival country becomes a competitive global producer, and then ban imports. However, as will be seen in the next section, this may no longer be the case when the rest of the world (beyond countries a and b) is taken into consideration.

Subsidies

A subsidy to the fixed cost may help the domestic producer become active or become the global producer, as in Brander and Spencer (1985). It does so by lowering the domestic producer's break-even price $\hat{p}_{n,t}^{-i}$, which makes it possible for a monopolist to threaten lower prices in a potential (out-of-equilibrium) price war. For a given pattern of international trade, the subsidy amount is irrelevant, as it is financed with lump-sum taxes and does not affect production quantities.

A *fixed cost* subsidy has similar implications as an import ban in certain cases, but it is a more limited tool. For example, a subsidy may fail to deter the entry into the domestic market of a foreign producer with lower marginal costs, as it does not affect the intensive margin.

[18] Strategic interactions could depend on policies other than trade, such as requirements to transfer or share technology, but only if such transfer requirements can be used to penalize the technology leader after it has decided to ban exports. In our model, banning exports stops technology transfers; hence, this type of policies would have no teeth.

[19] There are different reasons why banning exports might be easier than banning imports. First, the government in the producer's country may have more control over the producer's networks or data than the government of the destination country (see Farrell and Newman, 2019, for a discussion of this asymmetry in the context of the internet and the Swift payment system). Second, domestic political economy considerations may make it harder to ban imports, which benefit all consumers, than banning exports, which disproportionately benefit the shareholders of digital good producers.

Appendix III describes the implications of *production* subsidies, which do affect the intensive margin but can lead to other inefficiencies. For example, subsidizing exports can facilitate the capture of foreign markets, but lead to excessive production from the point of view of the exporter country, which would be transferring part of its rents to foreign consumers.

D. Rest of the world

Next, the model is extended to add the rest of the world as a third economy (indexed c) that cannot produce the digital good ($A_{c,t} = 0$). Other than this technological difference, country c is modeled symmetrically as countries a and b. Appendix II shows the full specification of the static equilibrium with a rest of the world.

Modeling the rest of the world has key implications for the dynamic equilibrium, which are evident from the simulations presented in the next section. It increases the incentives for the leader to ban exports to the challenger, as the cost in terms of lost current market share is smaller and the benefit in terms of protecting future market share is higher. If the growth rate at the frontier is not higher for the laggard though ($g_a \geq g_b$), the technological leader will still prefer an import ban to an export ban, as in the two-country case. The result changes if the laggard can eventually surpass the technology level of the leader ($g_a < g_b$), in which case an export ban can be the optimal policy even when import bans are available. This is because by the time the challenger becomes a competitive global producer and so an import ban becomes binding, its technology may already be too advanced to prevent it from entering the rest of the world market for long. In this case, the export ban is more effective in delaying the technological leapfrogging by shutting off technology flows to the challenger earlier on.

E. International financial integration

Domestic residents may own shares in foreign suppliers of digital goods. For simplicity, assume in period $t = 0$ country i's representative consumer owns a claim to a fraction $\phi_i \leq \frac{1}{2}$ of the profits from the supplier in country $-i$, and vice versa. This implies that the budget constraint for country i's consumer becomes:

$$C_{i,t} = w_{i,t} l_{i,t} + \pi_{i,t}^{f} + (1 - \phi_{-i})\Pi_{i,t} + \phi_i \Pi_{-i,t}.$$

The rest of equations remain unchanged.

As can be seen in the budget constraint, ownership of the foreign monopoly ($\phi_i > 0$ and $\phi_{-i} > 0$) compresses the consumption (and utility) gap between different trade patterns, associated with varying relative profits at home $\Pi_{i,t}$ and abroad $\Pi_{-i,t}$. Hence, it reduces the state space where it is optimal to ban trade, i.e., broad sharing of the gains from technological progress can mitigate trade tensions.

III. Illustrative Scenarios

Next, the evolution of the economy is described for two illustrative calibrations meant to capture the dynamics between 1) the US and the EU, and 2) the US and China, together with a passive rest of the world. For the purposes of the simulations and to elaborate the dynamics and incentives at play, the US represents the initial technology leader, China represents the potential challenger that could overtake the US, and the EU represents a technology follower that probably will not overtake the US. The free trade scenario is compared to the application of trade restrictions and subsidies. Table 2 contains the main calibration parameters, although alternative parameter combinations are also explored.[20]

Table 2. Calibration

Parameter	symbol	US	EU	China	RoW
Market size (= population)	L_i	1	1.1	1.5	4
Initial technology	$A_{i,0}$	1	0.9	0.2	-
Technological diffusion rate	σ_i	0.05	0.02	0.05	-
No-digital technology	B		1		
Digital good share	α		0.3		
Fixed cost	K		0.8		
Cyberattack rate	ρ		0.02		
Intertemporal discount factor	β		0.99		
Frontier growth rate	g		1.067		

Note: The technological diffusion rate to the US σ_{US} only applies to the case where China is assumed to have a higher frontier growth rate (Table 3).

US vs EU

The US is assumed to start with a small technological advantage, and technology diffusion to the EU is assumed to be small.[21] Population (proportional to market size in the model) is slightly larger in the EU.

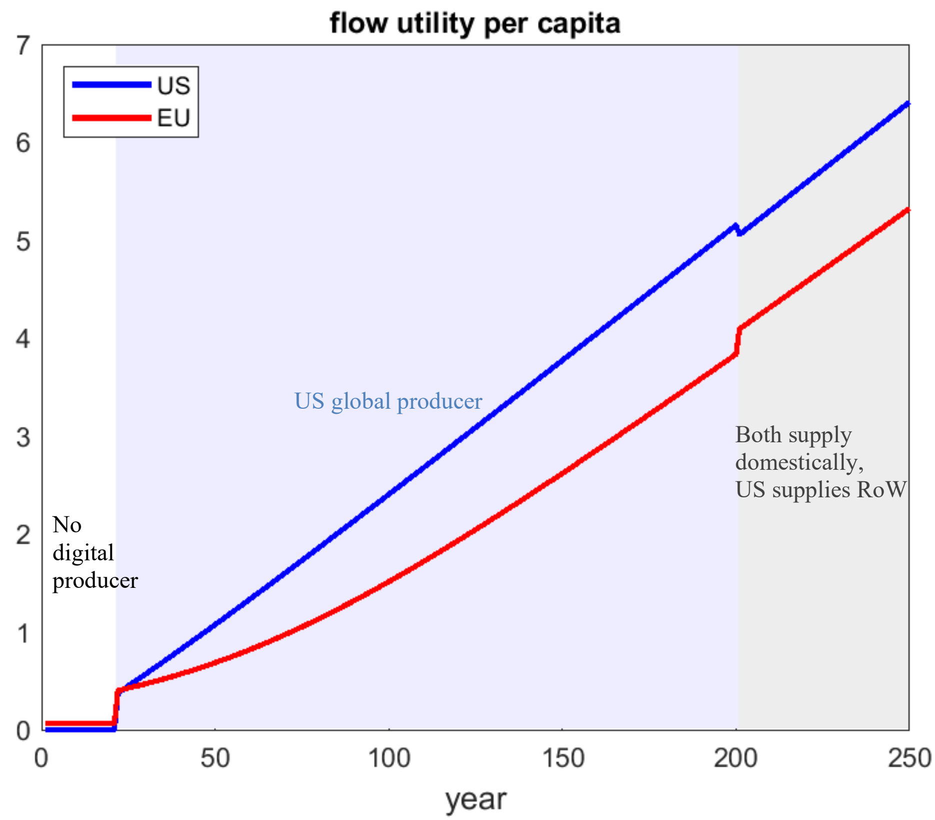
Figure 1 plots the evolution of flow utility per capita in each country and trade patterns for the digital good, under free trade. Initially, neither country is productive enough to pay the

[20] Market size (proportional to population in the model) is approximately calibrated to relative PPP GDP levels. Initial technology rates and the fixed cost are selected to illustrate a complete cycle of technological leapfrogging. The value for g implies GDP per capita growth of 2 percent ($\alpha * (g-1)$) as time tends to infinity. The calibration of σ ensure realistic growth patterns in China and the EU. The digital goods share is calibrated to the capital share. The value of $\rho = 0.02$ implies a cost of cybercrime at 0.4 percent of US GDP, which is below recent estimates (McAfee, 2018). The intertemporal discount rate $1/\beta$ is relatively low in line with current risk-free rates close to zero.

[21] This could be motivated for instance by the strong enforcement of intellectual property rights in the EU.

fixed cost of the digital good. Eventually, the US becomes productive enough and starts supplying it globally. As time passes and technology keeps growing, fixed costs as a share of output shrink, so both countries become domestic producers. This can be globally optimal given the presence of the cyberattack probability, which adds a cost to trade in digital goods (see Appendix I for more detail on the first best). Note the EU never becomes the global producer or challenger to the US, as its technology does not catch up fast enough.

Figure 1. Domestic utility under free trade, US vs EU

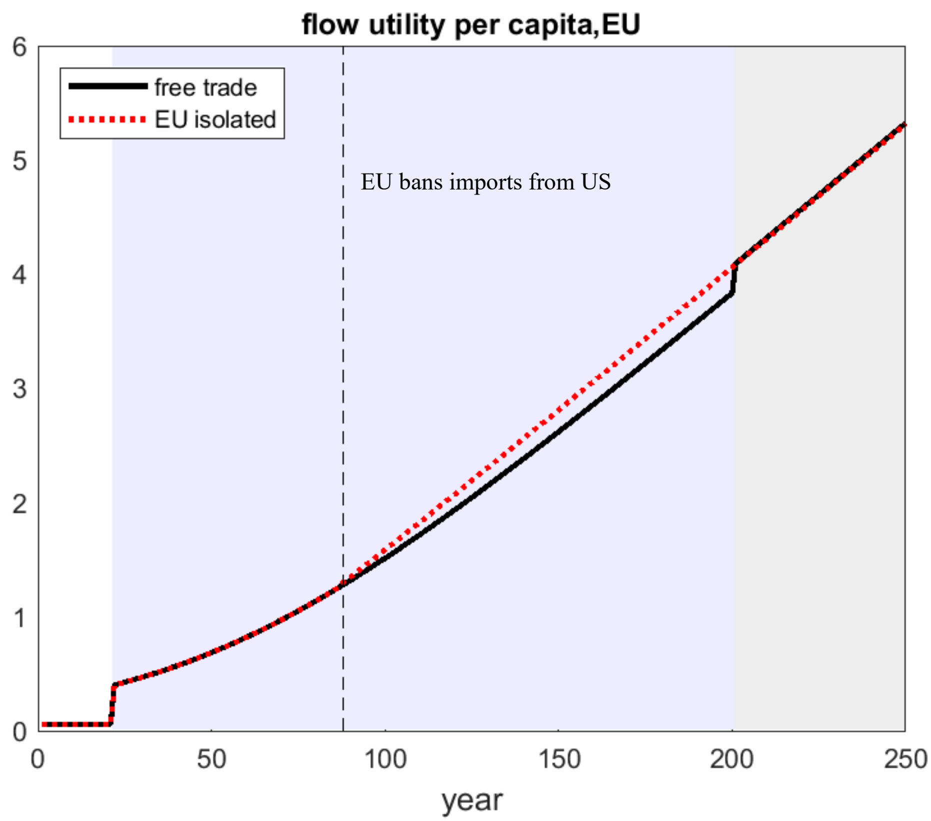


Notes: shaded areas indicate the trade pattern in digital goods.

In this setup, it may be optimal for the EU to ban US imports if it gets to a point where it has a profitable domestic producer in isolation, so it can stop paying monopoly rents to the US. Recent proposals in the EU could be interpreted as efforts to this end, including attempts to produce national or EU-wide champions, introduce a digital tax that under current trade patterns would affect foreign suppliers disproportionately more, or—regarding digital imports from China—directly delink them from the supply chain.

Figure 2 shows the optimal time for the EU to ban imports and the associated flow utility compared to the free-trade baseline. The optimal time is a few periods after the EU domestic producer becomes profitable, as initially the benefits from keeping technology inflows dominate. The US is assumed to respond to the EU's import ban by also banning imports from the EU; otherwise, the EU might have the opportunity to replace the US as the global producer by exploiting economies of scale. The reciprocal EU and US bans will lead to lower flow utility in the US relative to the free trade outcome. Since the EU does not have the potential to become the global producer or to threaten the rest of the world market, it is never optimal for the US to ban its exports.

Figure 2. EU utility, free trade vs EU ban



Notes: "EU isolated" refers to the case where the EU bans digital goods imports in years after the vertical dashed line. Shaded areas indicate the trade pattern in digital goods under free trade, as in Figure 1.

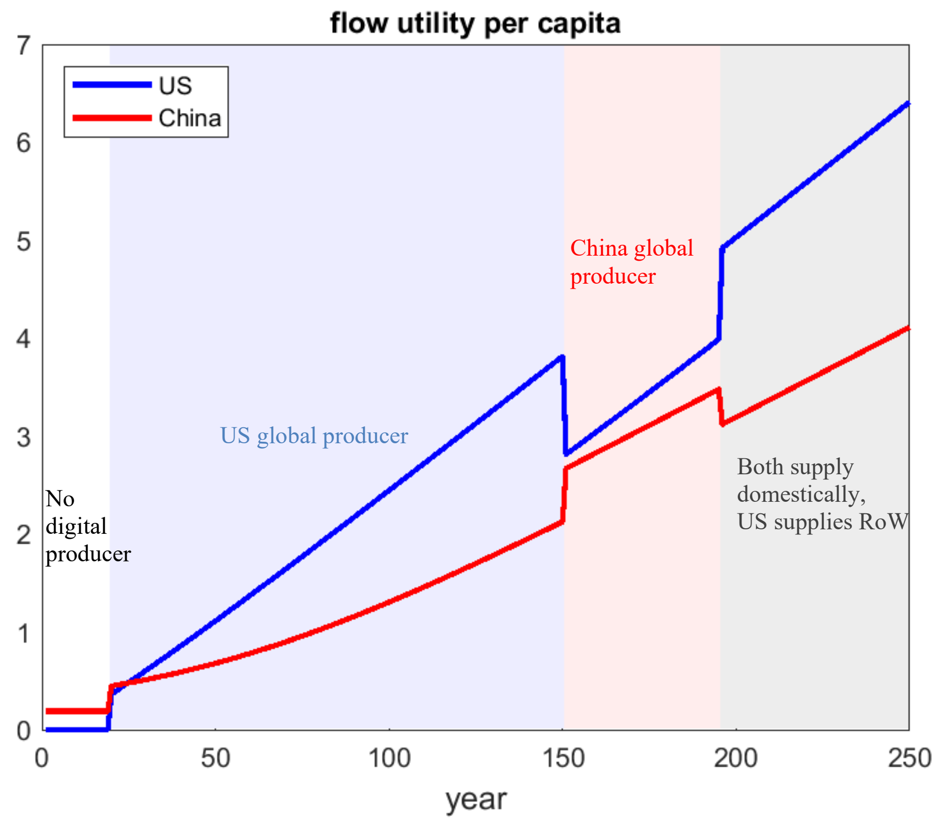
US vs China

The US is assumed to start with a significant technological advantage but has a smaller population. China gradually adopts technology from the US during periods when it is connected to global digital goods or networks (either as an importer or as a provider).

Figure 3 plots the evolution of utility per capita in each country and trade patterns for the digital good. This case is more complex than the US vs EU scenario. As before, at some point, the US becomes sufficiently productive and starts supplying the digital good globally. However, this triggers—by assumption—technological diffusion to China, which eventually becomes a more competitive provider as its profits as a global producer surpass those of the US. This happens even though China never reaches US productivity because with a sufficiently high trade friction ρ it becomes more efficient that the largest market (China) is supplied domestically, as this minimizes total costs.[22]

The moment when digital good provision shifts from the US to China, the US suffers a discontinuous fall in its flow utility, as it loses monopoly rents and becomes vulnerable to cyberattacks ($\rho > 0$).[23]

Figure 3. Domestic utility under free trade, US vs China



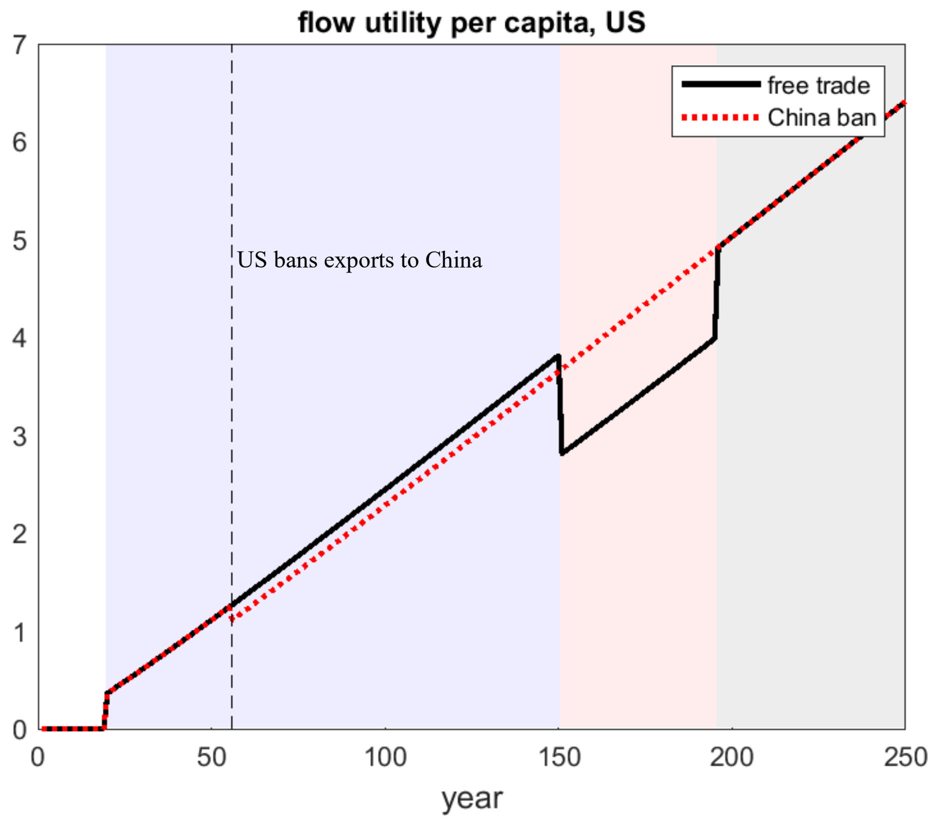
Hence, for plausible parameters, it is optimal for the US to delay this moment by stopping exports to China in previous periods and renouncing those earlier monopoly rents. A recent example of such policy by the US is the requirement that its companies do not export high-tech wares to blacklisted Chinese entities, in force since October 2019. Figure 4 compares the flow utility for the US under free trade and under a ban to digital good exports that enters into force from period $t = 56$ onwards (the optimal timing for this calibration). If the net

[22] A report by the McKinsey Global Institute (2019) estimates that China already features the world's largest consumer market in many technological goods.

[23] Note though that, as the relative importance of fixed costs fades over time, the US may be able at a future point to once again become the supplier to the rest of the world owing to its technological advantage (assuming the growth rate of China and the US are similar; this is elaborated further below). This is a knife-edge result, however, and could go either way depending on how competition is modeled.

difference between the "free trade" and "China ban" utility paths is negative (after applying the intertemporal discount rate), then it is optimal for the US to ban exports. However, an export ban is negative for global welfare, as it either implies that China loses access to the digital input or that the fixed cost is incurred twice if China produces domestically.

Figure 4. US utility, free trade vs China ban

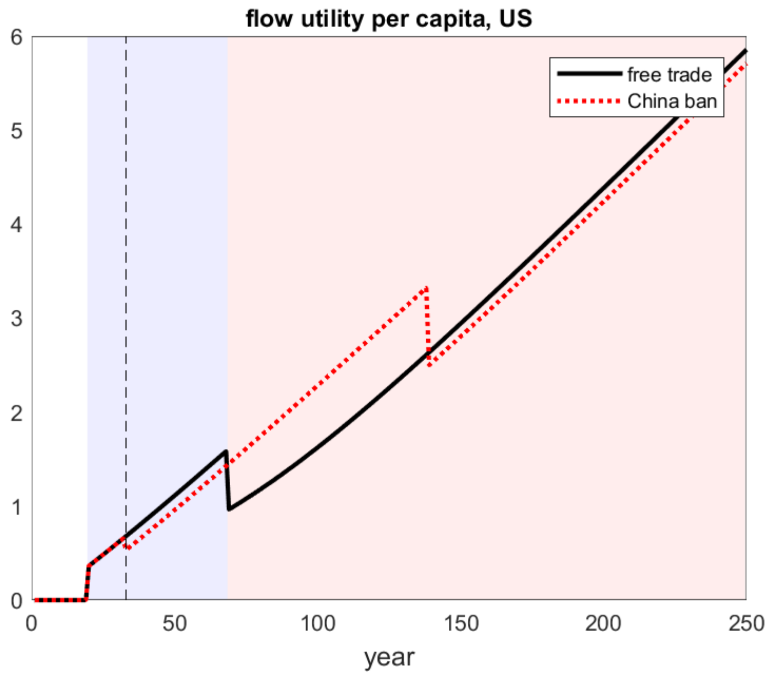


Notes: "China ban" refers to the case where the US bans digital exports to China, which applies to years after the dashed vertical line. Shaded areas indicate the trade pattern in digital goods under the free trade baseline, as in Figure 3.

The intrinsic growth rates of the US and China matter crucially. For the calibration where the US and China have the same intrinsic growth rate, an appropriately timed import ban could be better for the US than an export ban (Table 3). This is because under this calibration China never fully catches up with US technology, and so the US can permanently deter Chinese entry in the rest of the world market by not allowing it to gain adequate scale and become a global producer. If the US follows that strategy, China may want to anticipate it by banning US imports and becoming self-sufficient earlier on, as in the EU vs US case discussed above.

If instead China's intrinsic growth is expected to be higher than the US's (Figure 5), the result can be overturned. Table 3 displays the payoffs of both policies if China's frontier growth is half a percentage point above the US value. This is sufficient to make the export ban better for the US than an import ban, as it manages to keep China out of the rest of the world market for substantially more periods. Importantly, this result holds even if China does not reciprocate import bans. If it did, the advantage of export bans for the US would be even greater.[24]

Figure 5. US utility, free trade vs China ban, higher growth in China



Notes: Intrinsic growth in China is assumed to be 0.5 percentage points higher than in the US. "China ban" refers to the case where the US bans digital exports to China, which applies to years after the dashed vertical line. Shaded areas indicate the trade pattern in digital goods under the free trade baseline.

Table 3. Impact of US trade restrictions on utility under different Chinese growth rates
(percentage deviation in NPV of per capita utility relative to free trade)

Intrinsic growth (g)	US policy	US utility	China utility	World utility
Same for US & China	Export ban	0.6	-6.1	-1.3
	Import ban	3.2	-2.8	-0.1
+0.5% for China	Export ban	4.5	-16.0	-4.4
	Import ban	3.8	-3.3	-0.3

Note: this assumes China does not impose any trade restrictions, which would make import bans even worse for the US. The US optimizes the timing of its export and import bans. The case with higher intrinsic growth for China assumes that $g_c = g_u + 0.005$.

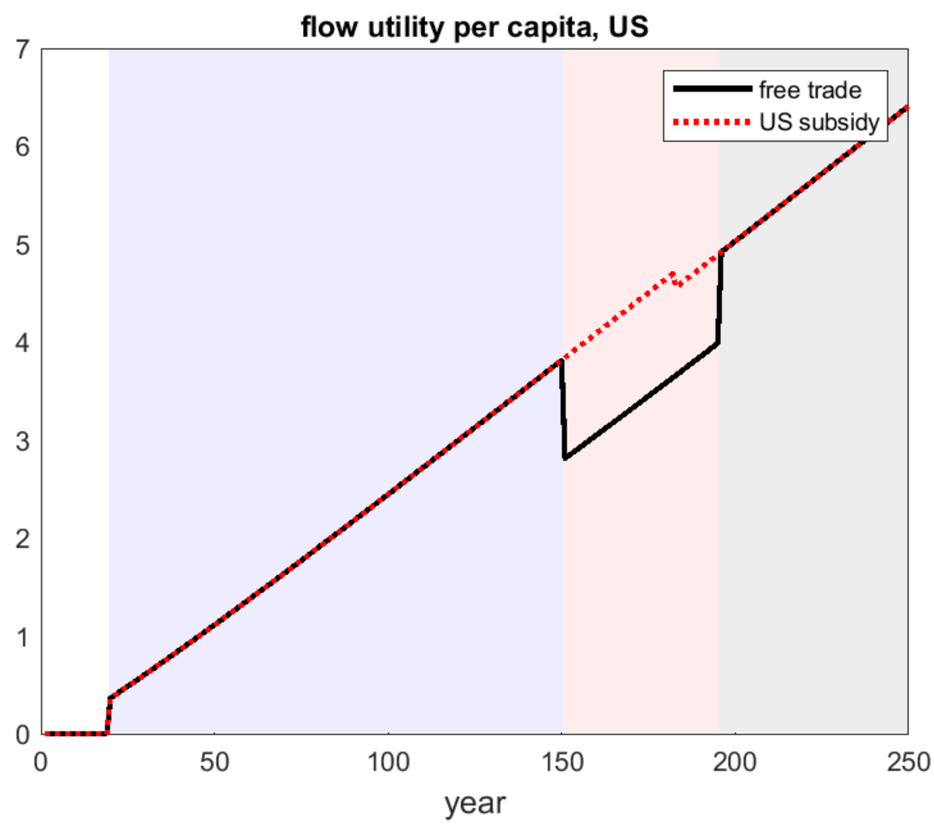
In both cases above, the technology transfer channel becomes an unambiguously positive force for the US once China leapfrogs it and becomes the global supplier. If China has leapfrogged the US, technology transfers flow toward the US, which becomes helpful by the time all countries start producing domestically. Otherwise, if China is still technologically

[24] Note in Figure 5 the imposition of an export ban to China lowers the US long-run utility level, as slowing the time China leapfrogs permanently shifts down the technological frontier. This was not the case in Figure 4 because with $g_c = g_u$ the frontier expands at the same rate no matter which is the leading country.

inferior despite being the global supplier, it is in the interest of the US to keep transferring technology to China so as to benefit from cheaper imports.

Returning to the calibration with equal intrinsic growth in the US and China, trade restrictions are not the only way for the US to improve upon the free market equilibrium. A subsidy to the fixed cost of the US producer has similar implications as an import ban, so it can yield higher discounted utility than an export ban (Figure 6 and Table 4). The small step down in the dotted line in Figure 5 corresponds to the period when China becomes a profitable domestic producer. However, unlike an export ban, a subsidy is vulnerable to reciprocation from China.

Figure 6. US utility, subsidy to US digital good producer



Notes: "US subsidy" assumes that the US government subsidizes the fixed cost of its domestic producer starting in period 150. Shaded areas indicate the trade pattern in digital goods under the free trade baseline, as in Figure 3.

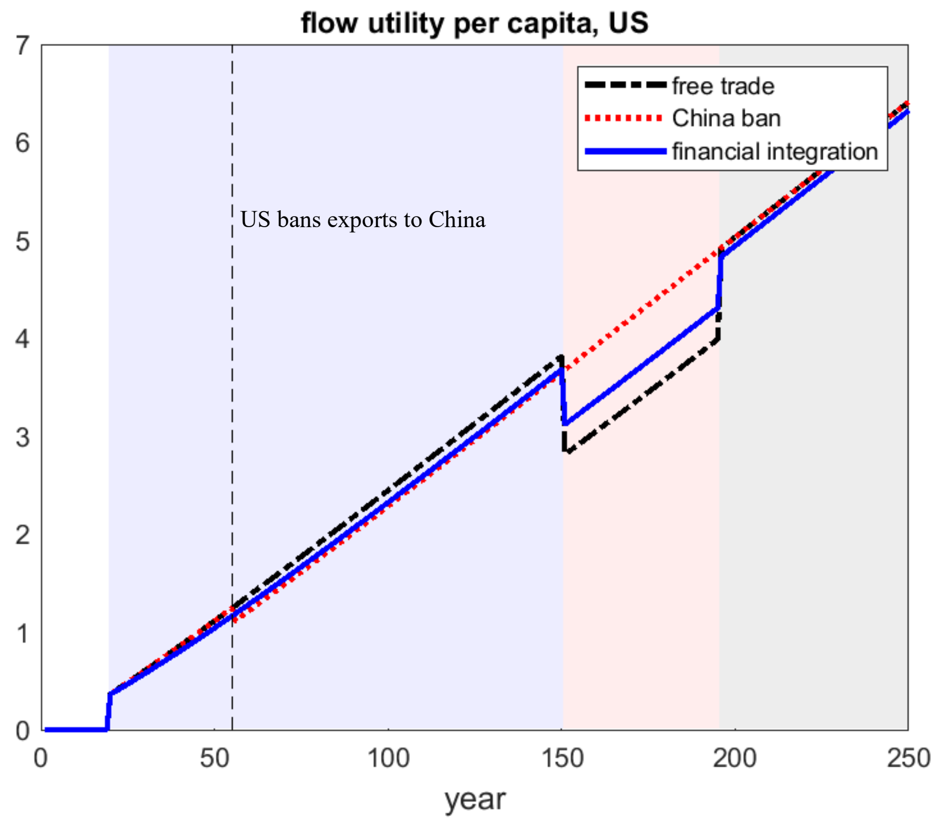
Table 4. Impact of policies on utility
(percentage deviation in NPV of per capita utility relative to free trade)

US policy	US utility	China utility	World utility
Export ban	0.6	-6.1	-1.3
Subsidy to fixed cost	3.2	-2.8	-0.1

Note: assuming China does not impose any trade restrictions. The US optimizes the timing of its export ban and subsidy.

Both international integration and cooperation can discourage trade restrictions. Figure 7 shows how financial integration in the form of cross-ownership of digital good producers aligns the utility of both countries, making an export ban undesirable. This is because Chinese losses from an export ban are greater than US gains, and financial integration makes governments act more like a global social planner. The figure shows the implications of cross-shareholdings of 15 percent. Larger crossholdings would further align utilities, with full alignment at 50 percent (not shown in the figure).

Figure 7. US utility, financial integration



Notes: "financial integration" assumes that 15 percent of shareholdings in the US producer are owned by Chinese residents, and vice versa. Shaded areas indicate the trade pattern in digital goods under the free trade baseline, as in Figure 3.

International cooperation could also take the form of rules preventing technological theft or cyberattacks. Table 5 shows how, as is the case of financial integration, changes to such parameters can diminish the benefits of an export ban. Interestingly, lowering the technological diffusion parameter can end up increasing diffusion in equilibrium if it succeeds in defusing trade conflict, as it would mean that technology transfers can flow during more periods. On the other hand, this would also increase the incentives to ban imports, particularly for the laggard country (China), which would no longer benefit as much from trade-related technological diffusion. Hence, the overall effect on trade will depend on the type of trade restriction that is more relevant in practice.

Lowering the rate of cyberattacks reduces the incentives for import and export bans, as it makes foreign producers relatively more competitive. Nevertheless, eliminating cyberattacks ($\rho = 0$) need not eliminate incentives for bans, because monopoly rents can still be earned.

Finally, if the future is discounted more heavily, export bans are less attractive. Thus, a political decision-making process that prioritizes a longer-term view may be more inclined to this kind of trade conflict. For instance, if multinational businesses—that invest in a large protected market and share technology in the expectation of eventually accessing the market—realize that their chances of accessing the market or competing in third markets are diminishing, they may argue for export bans from a longer-term perspective. The current global environment with low expected real rates far into the future would be particularly propitious for such bans.

Table 5. Impact of export ban on US utility under different parameters
(percentage deviation of NPV per capita utility relative to free trade)

	Parameter changed	US utility
Baseline	-	0.58
Financial integration	$\phi = 0.2$	-0.28
Lower tech theft	$\sigma = 0.04$	-2.00
Less cyberattacks	$\rho = 0.005$	0.24
More intertemp. discount	$\beta = 0.98$	-1.79

Note: Each calibration changes only one parameter with respect to the baseline. The timing of the export ban is reoptimized for each calibration.

IV. Discussion of the Results and Policy Implications

The paper has provided an economic framework to understand and evaluate the trade tensions between the United States and China, ongoing conflicts over technology access or transfers, intellectual property rights, and cyberattacks. It has done so by introducing a digital input into an otherwise standard production framework. The provision of the digital input bestows large monopoly profits, and its use is accompanied not only by technological diffusion but also cybersecurity risks.

Several results have emerged that are useful to review. First, in line with a long international trade literature on increasing returns to scale production, a country with a profitable domestic producer of the digital technology may find it optimal to ban its imports. This may be the case even if domestic production is relatively inefficient. The key motivation is to repatriate monopoly profits that would otherwise accrue to foreign shareholders. The attraction of import bans is reinforced by the presence of cybersecurity vulnerabilities, which—in economic terms—are essentially a trade friction that is not fully absorbed by a foreign monopolist and increases the cost of sourcing the digital good from abroad. Banning imports carries costs of halting technological diffusion and, thus, involves a forward-looking perspective. Only those capable of producing domestically or globally would consider banning imports. Those unable to do so would prefer free trade as otherwise they could not access the digital technology.

A second result, which is novel, is that a technology leader may find it optimal to ban exports of its digital good to a challenger, irrespective of the trade policies of the challenger. International technology diffusion and domestic scale economies can allow the challenger to come to a point where it can successfully displace the leader as the global producer and capture monopoly rents. To forestall such an event and reduce the concomitant cybersecurity vulnerabilities, the leader may seek to ban exports of the digital good.

An export ban trumps an import ban from the perspective of the leader if the technological growth of the challenger is expected to outpace that of the leader. This is because the export ban effectively delays the inevitable moment when the challenger's technology overtakes the leader's and thus minimizes the leader's losses of monopoly profits. By contrast, an import ban becomes binding only when the challenger has become a global producer, by which time its technology may be too advanced to prevent it from competing successfully in third markets, i.e., the rest of the world.

In the case of similar technological growth rates in the leader and challenger, however, the converse result emerges. Since the challenger's technology will not inevitably dominate the leader's in third markets, the leader can impose import bans to limit the challenger's scale economies and, hence, restrict catch up. It can, thus, expect to continue extracting monopoly profits from third markets.

While export bans benefit the leader relative to the free trade outcome, global welfare falls, as either the challenger loses access to the digital input or production is inefficient owing to duplicated incurrence of the fixed costs by the leader and the challenger. Moreover, a corollary of the result that the technology leader would impose export bans irrespective of the challenger's trade policies is that relying on retaliatory trade policies will not be effective in overturning the bans.

Subsidies to digital goods producers to offset the fixed costs are an option similar in effect to import bans. They can benefit domestic producers and lower the price at which they can successfully compete. But foreign monopolists could respond in kind to deter, undoing the gains that might otherwise be expected.

Given that export or import bans are rationalized over free trade outcomes in the quest for technological leadership and monopoly rents, perhaps the most compelling change will come if or when the natural monopoly properties of producing the digital good diminish. In the model, this is akin to reducing the fixed cost of producing the good relative to the size of the economy.[25] This in turn will require investment and technological developments.

International cooperation can help reduce incentives for beggar-thy-neighbor policies. These policies are deleterious from a global perspective, not least because they can slow

[25] In practice, this may not be possible for all digital activities, as increasing returns to scale are not only caused by fixed costs but also by other drivers such as network externalities, which may not fade away with growth.

technological progress, economic growth, and income convergence. Fostering a collaborative approach across industrial systems, facilitating cooperation among large numbers of scientists and experts, and enabling market access to reap economies of scale could maximize global welfare.

Dimensions over which cooperation is vital are regulatory policies, protection of intellectual property rights, cybersecurity, and cross ownership or cross shareholdings that could allow for aligning incentives. Consider each in turn.

If consideration is given to breaking up large domestic technology firms to reduce their monopoly profits or otherwise regulating prices, then—from the perspective of the framework above—this should ideally be done in concert across nations. If only one country moves toward strong regulation while foreign monopolists are free to compete, then the country could risk falling behind in the race for technology and markets.

Technological leadership is determined—not surprisingly—by the rate of technological change. Whoever successfully achieves and maintains the highest rate of technological change at the frontier will come out ahead and earn monopoly profits; others would benefit via diffusion and the world at large would benefit from cheaper and better products. While not modeled specifically here, the large literature on endogenous growth suggests prioritizing investment and securing intellectual property rights. The latter would benefit innovators everywhere, regardless of who eventually emerges as or remains the technology leader.

Minimum enforced standards would thus be in everyone's interest and would reduce concerns about misuse, forced transfers, or theft. In the model, this is governed by a standard diffusion parameter. Reducing forced transfers and theft would reduce the incentives for the technological leader to impose export bans. It would thus allow for longer periods for diffusion and higher welfare globally. First steps toward defining global standards include fostering cooperation or coordination and building trust. This should be coupled with trade policy agreements to avoid reciprocal import bans, whose attractiveness would rise.

A complication in the cyber era is that innovation and intellectual property need not be solely in the domain of the private sector. The harvesting and use of big data, cyber surveillance, espionage, and hacking are among the activities associated with several state actors, who may also seek to partner with domestic private firms for mutual benefit (see Sanger 2018 and Clarke and Knake 2019). There is therefore an urgent need for uniform rules of the game with transparent and effective enforcement, perhaps with narrow and clearly demarcated areas of national security concerns and where domestic public-private partnerships are deemed acceptable. This could include adoption and enforcement of cybersecurity best practices. International public-private partnerships could also be encouraged. In this regard, the fact that sizable innovation occurs across geographic boundaries should be leveraged (see, e.g., World Intellectual Property Organization, 2019). Setting technological standards could potentially also support enforcement of rules in cyber space (e.g., ISO20022, which is an international standard for electronic data interchange among financial institutions supporting payments).

A related area for strong cooperation is cybersecurity. An analogy from Moore et al. (2009) is instructive: with the advent of motor cars over a century ago, criminals began using cars to commit crimes in different towns where the police would not recognize them and get away. It required new organizations of policing across town and state boundaries, along with new technologies such as finger printing, to combat this crime. Similarly, the advent of the internet has facilitated an explosion in cross-border online crime, but for which the national and international tools, norms, and organizations have yet to be firmly established. There have been important efforts at cooperation on cybersecurity, particularly in bilateral or regional arrangements (e.g., Interpol, within the EU). But complications to greater or effective cooperation include competing interests among participants, national security considerations, differences in judicial and criminal systems, and concerns over misuse by governments. There is also no international court on criminal issues (apart from the International Criminal Court for major international crimes).

This has led to calls for a new Bretton Woods moment for the digital age, with the appropriate institutions to collectively address and resolve the new challenges (see, e.g., Balsillie, 2018, and Tett, 2019). International structures currently attempting to deal with these challenges include the International Telecommunications Union and the UN Commission on International Trade Law. There is also active, albeit high-level, involvement by a wide range of actors, including the G7, OECD, and to some extent the IMF. But clearly a more concerted effort is needed. In the model, reducing the probability of cybercrimes lowers the incentives for export bans. It does not eliminate it, however, because of the existence of monopoly rents.

Yet another area for international cooperation is in facilitating foreign ownership and control of monopolistic digital goods providers. This would help broad sharing of the rents that accrue, align incentives for better outcomes, and dismantle incentives for trade conflict—a result that emerges clearly in the model. Pre-requisites would be open financial or capital accounts to permit such ownership, governance arrangements that would facilitate control, upholding of foreign property rights, and as noted above narrow and well circumscribed areas where national security arguments may be used. In this regard, cooperation to facilitate cross-border listings of stock would be recommended.

V. Conclusion

Since World War II, no one has come close to challenging the US's global technological or economic leadership, save most recently China. The erstwhile Soviet Union challenged the U.S. on military and space technology, which required heavy state involvement. Beyond that, where competitors have arisen and where technologies developed or deployed mainly by the private sector were concerned, these were invariably in select sectors or involved partners that benefited from the U.S.'s security umbrella. China is the first to compete on scale and across new technologies, while not being part of the U.S.'s security blanket. This has raised new issues for the globally integrated trading and monetary system.

This paper has presented a framework to shed light on some of the key dynamics at play recently. It has accounted for the imposition of export or import bans on certain new general-purpose technologies—termed decoupling—as part of a race for technological and economic leadership and capturing or safeguarding monopoly rents in domestic and global markets. It has also incorporated concerns that have been expressed about cross-border cybersecurity.

The findings are sobering. If large monopoly rents are on offer in certain sectors, incentives will be strong for imposing export or import bans and, hence, decoupling, which is damaging for global welfare. These incentives can be weakened by collaborating effectively on cybersecurity norms, institutions and policies; strictly delineating state involvement to a narrow set of activities; and facilitating cross-border ownership of private monopolists or providers. But they may not be entirely overcome until the monopoly rents on offer reduce. Therefore, it will probably require monumental efforts to focus on the broader public good and overcome domestic pressures to try to get ahead of the competition, including if cyber warfare is seen as the key arena for security conflicts in the future.

The framework in the paper is parsimonious to allow for a sharp focus on the key factors of interest. One extension is to examine how export or import bans in certain new general-purpose technologies may be leveraged to impact trade in other goods and services. If many other areas of trade are impacted, broader decoupling may follow. But promoting conditions under which the bans might be more narrowly circumscribed could limit the extent of decoupling that may be involved. Another extension is to study the implications of substituting between the technologies of the different competitors or the ease of simultaneously using them. Depending on the ease of substitution or simultaneous use, the rest of the world may be forced to pick sides. This would impact the scale economies that the competitors can achieve and could lead them to try and influence the choices of the rest of the world. It could also help to discern the benefits of defining common global standards for the development of new digital technologies. Finally, trade restrictions, by altering market access, could affect the incentives to invest in technological growth, thus creating a feedback loop between policy and technology.

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APPENDIX I: FIRST-BEST ALLOCATION

The social planner chooses quantities to maximize the net present value of world utility, which is the sum of countries' utilities:

$$\max_{c_i,y_i,n_i,l_i} U_{w,t} = \sum_i U_{i,t},$$

subject to the resource constraints.

Static equilibrium

The optimal quantity of the digital good produced in country i is equivalent to eliminating the monopoly markup and setting prices equal to marginal cost:

$$n_{i,t}^{j} = \left(\left(1 - \rho * I(i \neq j)\right)\alpha A_{i,t}\right)^{\frac{1}{1-\alpha}} l_{j,t}$$

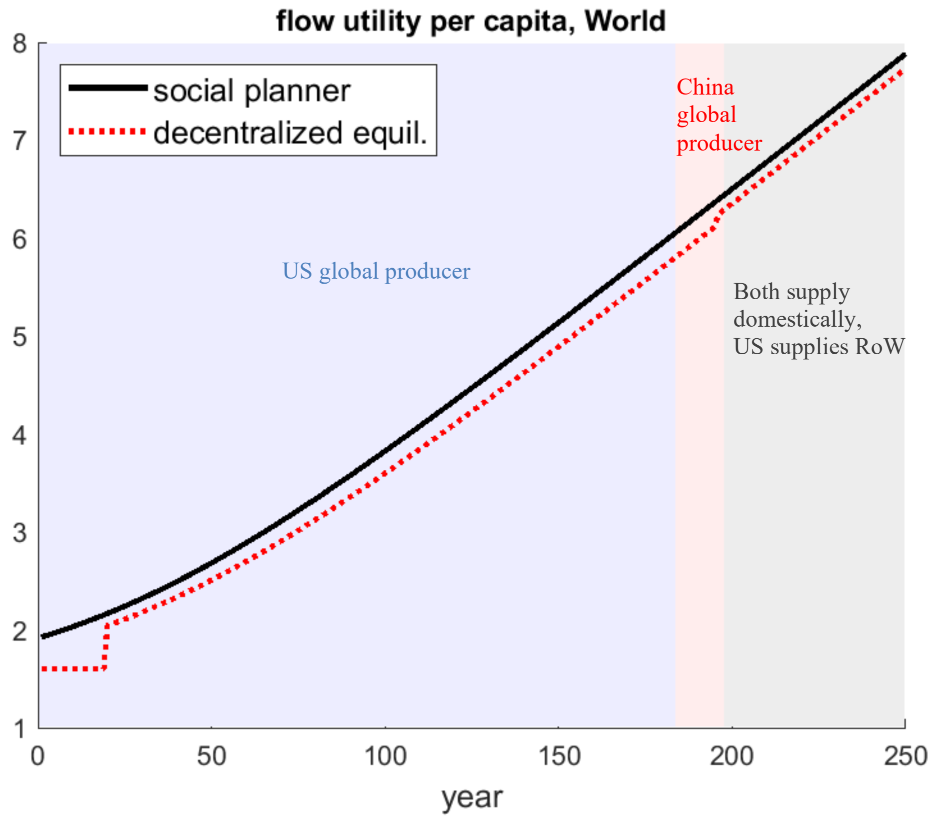
as long as the incremental cost of supplying country i is smaller than the surplus, and $n_{i,t}^{j} = 0$ otherwise. The rest of static conditions are as in the decentralized equilibrium.

Dynamic equilibrium

As in the decentralized economy, the dynamic equilibrium must be solved numerically. Intuitively, the planner will weigh the benefits of trade—lower incurrence of fixed costs and higher technology diffusion—against its costs—higher trade frictions or cyberattacks. Compared to the decentralized equilibrium, trade is unambiguously more likely under the social planner, as two of the motives for trade restrictions disappear: monopoly rents and preventing technological flows to a laggard.

Figure 8 compares the global utility paths under the social planner and the decentralized equilibrium with free trade, for the US vs China calibration used in Section III. The main reason why the global planner reaches a higher utility path is because it corrects for the static monopoly markup distortion. Second, it starts producing the digital good since period one, as the total surplus from production is higher than the monopolist surplus, making it easier to compensate for the fixed cost. Third, the US is a global producer for longer than in the decentralized equilibrium, as the motive to capture rents is now absent for China. Finally, for the same reason, it takes a few more periods for the US to return as a domestic producer in parallel to China.

Figure 8. World utility, social planner



Notes: Shaded areas indicate the trade pattern in digital goods under the social planner. The model is calibrated for the US vs China case as specified in Table 2.

APPENDIX II: MODEL WITH A REST OF THE WORLD

This Appendix lays out the model extended with the rest of the world, denoted as country *c*.

Set-up

The world is now formed by three countries: $i = \{a, b, c\}$. Country c cannot produce the digital good $A_{c,t} = 0$, which implies $n^j_{c,t} = \pi^j_{c,t} = \Pi_{c,t} = 0$. Other than these technological differences, country c is modeled symmetrically as a and b. Hence, all the model set-up equations in Section II.A still apply, using $i = \{a, b, c\}$ instead of $i = \{a, b\}$.

Static equilibrium

All static equilibrium conditions in Section II.B also apply, except for the entry conditions in digital good production. Absent any trade bans, the three possible production patterns for the digital good in equilibrium are: no production, one producer is the global producer, or one producer is domestic and the other serves its domestic market plus the rest of the world.

Condition b) in Section II.B that "a digital good producer from country i produces *only if* no foreign producer can profitably enter in any of the markets where the producer from country i is selling" still applies, but its specification changes. If country $i = \{a, b\}$ is to be a global producer, the potential producer from country $-i = \{b, a\}$ must be deterred from entering its own domestic market, and also from simultaneously entering its own domestic market and the rest of the world.[26] Hence, two conditions must now be checked.

As in the two-country case, entry is deterred if the potential producer from $-i$ cannot make profits when the global producer is selling at its minimum possible price, which is the maximum between its marginal cost and its break-even price. Formally, the minimum price is, as before:

$$\tilde{p}^j_{n,t} = \max\left\{\frac{1}{(1-\rho)A_{i,t}}, \hat{p}^j_{n,t}\right\},$$

where $j \neq i$. The difference here is that the break-even price $\hat{p}^j_{n,t}$ and associated profits for the potential entrant depend on how many markets the entrant is trying to enter.

If the entrant targets only its domestic market, the break-even price $\hat{p}^{-i}_{n,t}$ in that market for the incumbent is such that:

$$\pi^i_{i,t} + \pi^i_{c,t} + \left(\hat{p}^{-i}_{n,t} - \frac{1}{(1-\rho)A_{i,t}}\right) n\left(\hat{p}^{-i}_{n1,t}, l_{-i,t}\right) - K + \tau_{i,t} = 0,$$

and the associated entrant profits are non-positive if:

$$\left(\tilde{p}^{-i}_{n,t} - \frac{1}{A_{-i,t}}\right) n\left(\tilde{p}^{-i}_{n,t}, l_{-i,t}\right) - K + \tau_{i,t} \leq 0.$$

If the entrant targets its domestic market plus the rest of the world, then the incumbent needs to choose a minimum price in each of these two markets. Note the entrant has an advantage in its domestic market, so this is where the incumbent will try to lower its price the most, setting it equal to its marginal cost $\frac{1}{(1-\rho)A_{i,t}}$ and making zero profits. Then, the break-even price $\hat{p}^c_{n,t}$ in the rest of the world is such that:

$$\pi^i_{i,t} + \left(\hat{p}^c_{n,t} - \frac{1}{(1-\rho)A_{i,t}}\right) n\left(\hat{p}^c_{n,t}, l_{-i,t}\right) - K = 0,$$

and the associated profits are non-positive if:

$$\left(\frac{1}{(1-\rho)A_{i,t}} - \frac{1}{A_{-i,t}}\right) n\left(\frac{1}{(1-\rho)A_{i,t}}, l_{-i,t}\right) + \left(\tilde{p}^c_{n,t} - \frac{1}{(1-\rho)A_{-i,t}}\right) n\left(\tilde{p}^c_{n,t}, l_{c,t}\right) \leq K,$$

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[26] Entry cannot happen in the rest of the world only because a viable entrant in the rest of the world would also be more competitive as a domestic producer, as it would avoid the trade cost ρ in the domestic market.

where the first term captures domestic market profits and the second term profits in the rest of the world.

If both conditions above are satisfied, i.e., if profits for the potential entrant are non-positive under both entry strategies, then the global producer cannot be threatened by a non-global producer.

If both countries have potentially profitable global producers and none can be challenged by a non-global producer, then the one with higher potential expected profits $\Pi_{i,t}$ as a global producer prevails, as in Section II.B.

If no global producer is sustainable, and both domestic producers are profitable, the producer with the lowest potential price in the rest of the world captures that market, and the other one produces domestically. The lowest potential price for a producer in the rest of the world market is the maximum between its marginal cost in that market and its breakeven price when it serves the rest of the world and the domestic markets.

APPENDIX III: PRODUCTION SUBSIDIES

Section II discussed a subsidy to the fixed cost, while this appendix focuses on a subsidy proportional to the quantity produced in a market.

Domestic market

The government can subsidize the sales of digital goods in the domestic market, so the producer receives an amount $(1 + \tau_{i,t})p_{n,t}^{i}$ per unit sold.

From a purely static and domestic perspective, the optimal production subsidy is the one that induces marginal cost pricing: $\tau_{i,t}^{*} = \frac{1-\alpha}{\alpha}$, replicating the first best. However, subsidies may affect trade patterns and thus technology diffusion. For example, the optimal domestic subsidy from a static point of view could deter entry, which can be either positive or negative for welfare depending on the balance between monopoly rents and technology inflows. Still, a subsidy to the fixed cost is always a least costly way to alter trade patterns than setting a production subsidy different from $\tau_{i,t}^{*}$.

Foreign market

Similarly, the government can subsidize the sales of digital goods in a foreign market $j = \{-i, c\}$, so the producer receives an amount $(1 + \tau_{i,t})p_{n,t}^{j}$ per unit sold.

Subsidies to exports constitute a transfer of wealth to foreigners, so they can only be optimal if 1) they are able to open access to additional foreign markets (by lowering the sales price enough to drive out competitors) and 2) the same cannot be achieved with a fixed cost subsidy, which unlike an export subsidy is entirely recouped by domestic shareholders.