

Davis, Colin R.; Hashimoto, Ken'ichi

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**ASYMMETRIC TARIFFS AND
PRODUCTIVITY GROWTH
IN AN ENDOGENOUS MARKET
STRUCTURE**

Colin Davis
Ken-ichi Hashimoto

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The Institute of Social and Economic Research
Osaka University
6-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan

Asymmetric Tariffs and Productivity Growth in an Endogenous Market Structure

Colin Davis Ken-ichi Hashimoto
Doshisha University* Kobe University[†]

September 2024

Abstract

This paper constructs a two-country model to investigate how tariff policy influences productivity growth through adjustments in industry location patterns. The locations of production and innovation are determined based on trade barriers and imperfect knowledge dissemination. Tariff policy has the effect of attracting firms, reshaping the location of industry, and the productivity of investment in innovation. We show that the relationship between tariff policy and economic growth depends on the industrial share of the country where the policy is implemented. In addition, examining the welfare effects of tariffs, we find that policy trade-offs may generate positive optimal tariff rates.

JEL Classifications: F43; O30; O40

Keywords: Tariff Policy, Industry Location, Knowledge Diffusion, Productivity Growth

*The Institute for the Liberal Arts, Doshisha University, Karasuma-Higashi-iru, Imadegawa-dori, Kamigyo, Kyoto, Japan, 602-8580, cdavis@mail.doshisha.ac.jp.

[†]Graduate School of Economics, Kobe University, 2-1 Rokkodai, Nada, Kobe, Japan, 657-8501, hashimoto@econ.kobe-u.ac.jp.

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1 Introduction

International trade frictions have escalated significantly over the past decade. The United States, for example, has expanded the share of Chinese exports subject to import tariffs to 66.4% with an average tariff rate of 19.3%. And, in retaliation, China has raised the share of U.S. exports subject to imports tariffs to 58.3% with an average tariff rate of 21.1% (Bown, 2023). Although the implications of rising trade frictions for economic growth have become a key concern (The Economist, 2018), unravelling the relationship between tariff policy and economic growth remains a complex challenge. Tariff adjustments not only disrupt trade flows but also influence the geographic location of industry (The Economist, 2016). And, a growing body of empirical literature highlights the implications of industry location patterns for economic growth (Gardiner et al., 2011; Desmet and Rossi-Hansberg, 2014).¹ Consequently, the recent escalation in trade frictions emphasizes the importance of analyzing how national trade policy shapes trade patterns, the location of production, and ultimately economic growth.

In this paper we consider how national tariff policy influences productivity growth through the link between industry location patterns and firm-level investment in research and development (R&D). Adapting the two-country framework of Davis and Hashimoto (2014, 2016), monopolistically competitive firms play a central role in the analysis, investing in process innovation to reduce future production costs (Smulders and van de Klundert, 1995; Peretto, 1996). Technical knowledge accumulates within the production technology of each firm, generating an intertemporal knowledge spillover that potentially leads to perpetual economic growth (Romer, 1990). Firms independently select optimal locations for production and innovation. Then, international trade barriers in the form of iceberg transport costs and import tariffs, generate a home market effect (Krugman, 1980) that results in the geographic concentration of industry in the country with the larger market (Martin and Ottaviano 1999, 2001). In addition, im-

¹Baldwin and Martin (2004) provide an overview of the new economic geography literature.

perfect international knowledge diffusion links labor productivity in process innovation with the location pattern of production, with the geographic concentration of industry strengthening knowledge spillovers and reducing innovation costs. Accordingly, process innovation concentrates fully in the country with the greatest share of industry.

Using the framework to examine the effects of changes in national tariff policy, we find that increasing a tariff expands the industrial share of the implementing country. The tariff revenue of the implementing country initially rises with the higher tariff rate but then falls as the volume of imports contracts due to the relocation of industry. Naturally, the tariff revenue of the non-implementing country rises as the volume of imports expands. The implications for productivity growth and market entry depend on how the shift in the location of industry affects knowledge spillovers into innovation. On the one hand, when the implementing country has a relatively large share of industry, and hosts all process innovation, the tariff increase leads to greater industry concentration, strengthening knowledge spillovers. In response, firms increase investment in process innovation, accelerating the rate of productivity growth. On the other hand, when the implementing country has a relatively small share of industry, and hosts no process innovation, the tariff increase reduces industry concentration, weakening knowledge spillovers and slowing productivity growth. Import tariffs generally have an ambiguous effect on the level of market entry. Stronger knowledge spillovers tend to lower the number of firms in the market, as the increase in the cost of employing labor in innovation decreases firm-level profit. In addition, higher tariffs decrease industry-level profit reducing the number of market entrants.

The impact of tariffs on national welfare hinges on the interplay of three effects. First, increased industry concentration improves the welfare of both countries by accelerating productivity growth through a knowledge spillover effect. Consequently, a rise in the tariff rate of the large country tends to improve welfare through a positive knowledge spillover effect, while a tariff increase in the small country generally harms

welfare due to a negative knowledge spillover effect. Second, when a country raises import tariffs, it benefits from a positive price effect, as the average price of goods decreases due to a reduction in the share of imported varieties. In contrast, the foreign country experiences a negative price effect, with the average price of goods increasing as the share of imported varieties rises. Third, although domestic tariff revenues initially increase with higher tariffs, they eventually decline, whereas the tariff revenues of the foreign country continuously rise. Given these opposing knowledge spillover, price, and revenue effects, the overall impact of tariff increases on national welfare is ambiguous. A numerical evaluation of the framework indicates, however, that the welfare of the implementing country generally aligns with the revenue effect: it benefits from low tariff rates but is hurt by high tariff rates, suggesting a positive optimal tariff rate for both the large and the small country. In contrast, the foreign country always experiences a welfare deterioration under the examined parameter set.

Our analysis contributes to the literature studying the relationship between national tariff policy and innovation-based endogenous growth. This body of research generally concludes that uniform tariffs across symmetric countries reduce the returns to innovation, slowing economic growth (Rivera-Batiz and Romer, 1991; Dinopoulos and Segerstrom, 1999a, 1999b; Peretto, 2003). In a similar vein, Naito (2021) demonstrates that unilateral tariff reductions between asymmetric countries always raise long-run growth. If tariffs give rise to the reallocation of resources away from innovation, however, the rate of growth may decrease or increase depending on whether the implementing country has a comparative advantage in R&D (Grossman and Helpman, 1990). This finding suggests a role for industry location patterns, as the agglomeration of industry in more protected countries then promotes faster economic growth when labor productivity in innovation is linked with industry concentration (Baldwin and Forslid, 1999). Our analysis extends the literature by exploring how unilateral tariff policy influences economic growth within an endogenous growth and endogenous market structure frame-

work (Smulders and van de Klundert, 1995; Peretto, 1996, 2003). We demonstrate that the endogenous determination of industry location patterns leads to asymmetries in the effects of national tariff policy on growth.²

A closely related strand of literature considers the effects of unilateral trade policy within the North-South product cycle framework introduced by Grossman and Helpman (1991). In this model, the developed North introduces new higher quality products while the developing South imitates existing ones. Production shifts between regions, as the North innovates while the South imitates specific product lines, resulting in product-cycle trade dynamics. Dinopoulos and Segerstrom (2007) conclude that uniform tariff policy does not influence long-run growth. Similarly, Grieben and Şener (2009) find that unilateral tariffs in either region do not affect growth in the base model. However, when they extend their model to include a non-innovative southern sector, they demonstrate that a unilateral increase (decrease) in northern (southern) tariffs can impact growth by reallocating resources between sectors lowering (raising) the growth rate. Iwaisako and Tanaka (2024) extend the product cycle framework to incorporate foreign direct investment, showing that when northern firms shift production to the South to take advantage of lower costs, a northern tariff can redirect production back to the North, raising labor costs and slowing growth. Conversely, a southern tariff encourages production to shift to the South, reducing northern labor costs and promoting growth.

The remainder of the paper proceeds as follows. Section 2 introduces the model structure and derives equilibrium production and innovation location patterns. In Section 3, we examine how import tariffs affect industry location patterns and productivity growth, and consider the implications for welfare. Section 4 then provides numerical evaluations of the welfare effects of tariff policy. Section 5 concludes.

²Davis and Hashimoto (2016, 2018) analyze the effects of economic integration and corporate taxes in two-country endogenous growth and endogenous market structure frameworks.

2 Model

We construct a model of industry location, international trade and endogenous productivity growth with two industries and two countries. The agricultural sector produces goods for a perfectly competitive market under free trade. In the manufacturing sector, firms produce differentiated product varieties for a monopolistically competitive market that features import tariffs and transport costs. Firms also invest in process innovation to lower future production costs, generating endogenous productivity growth. Free to shift production and innovation independently between countries, manufacturing firms locate each of these activities in their lowest cost locations. Labor is mobile across sectors, but there is no international migration.

2.1 Households

Each country is populated with dynastic households that choose optimal consumption paths over an infinite time horizon. Time (t) flows continuously, and the lifetime utility of a household residing in country i is

$$U_i(0) = \int_0^{\infty} e^{-\rho t} (\alpha \ln X_i(t) + Y_i(t)) dt, \quad i = 1, 2, \quad (1)$$

where $X_i(t)$ and $Y_i(t)$ are the consumptions of a manufacturing composite and the agricultural good, $\rho > 0$ is the rate of time preference, and $\alpha > 0$ is a parameter. The manufacturing composite has a constant elasticity of substitution (CES) formulation:

$$X_i(t) = \left(\int_0^{N_i(t)} x_{ii}(\omega, t)^\sigma d\omega + \int_0^{N_j(t)} x_{ij}(\omega, t)^\sigma d\omega \right)^{\frac{1}{\sigma}}, \quad i, j = 1, 2; i \neq j,$$

with $x_{ii}(t)$ and $x_{ij}(t)$ denoting household consumption in country i for each of the $N_i(t)$ and $N_j(t)$ product varieties produced in countries i and j . The degree of product differentiation is described by $\sigma \in (0, 1)$, and corresponds with a constant elasticity of

substitution across product varieties equal to $1/(1 - \sigma)$.

Lifetime utility is maximized subject to the following flow budget constraint:

$$\dot{A}_i(t) = r_i(t)A_i(t) + w_i(t) + Z_i(t) - E_i(t), \quad i = 1, 2,$$

where $A_i(t)$ is household asset holdings, $r_i(t)$ is the interest rate, $w_i(t)$ is the wage rate, $Z_i(t)$ is a lump-sum transfer from the government, and $E_i(t)$ is household expenditure in country i . A dot over a variable denotes differentiation with respect to time. Solving the household's dynamic utility maximization problem, we find that the optimal expenditure path is characterized by constant expenditure ($\dot{E}_i = 0$), and the interest rate therefore equals the rate of time preference in both countries at all moments in time; that is, $r_1 = r_2 = \rho$.

Adopting the agricultural good as the model numeraire, we set its price to one. Households allocate constant shares of expenditure across the agricultural good and the manufacturing composite: $Y_i(t) = E_i(t) - \alpha$ and $P_i(t)X_i(t) = \alpha$, where the price index associated with the manufacturing composite in country i is given by

$$P_i(t) \equiv \left(\int_0^{N_i(t)} p_i(\omega, t)^{\frac{\sigma}{\sigma-1}} d\omega + \int_0^{N_j(t)} ((1 + \tau_i)\zeta p_j(\omega, t))^{\frac{\sigma}{\sigma-1}} d\omega \right)^{\frac{\sigma-1}{\sigma}}, \quad i, j = 1, 2; i \neq j, \quad (2)$$

with the prices of varieties produced in countries i and j are denoted by $p_i(t)$ and $p_j(t)$. Trade is subject to an iceberg transport cost, under which $\zeta > 1$ units must be shipped for every unit sold in the export market (Samuelson, 1954). In addition, a tariff τ_i is levied on goods imported into country i on a cost, insurance and freight basis. Applying Shephard's Lemma to the price index (2), we derive the product demands from households in country i :

$$x_{ii}(\omega, t) = \frac{\alpha p_i(\omega, t)^{\frac{1}{\sigma-1}}}{P_i(t)^{\frac{\sigma}{\sigma-1}}}, \quad x_{ji}(\omega, t) = \frac{\alpha ((1 + \tau_i)\zeta p_j(\omega, t))^{\frac{1}{\sigma-1}}}{P_i(t)^{\frac{\sigma}{\sigma-1}}}, \quad i, j = 1, 2; i \neq j, \quad (3)$$

for representative product varieties produced in countries i and j .

2.2 Production

The agricultural sector employs a constant returns to scale technology, with one unit of labor required for each unit of output. Market competition then ensures that the price of agricultural goods equals the wage rate. Thus, as we have set the agricultural good as the model numeraire, and assumed free trade between countries, the wage equals one in both countries at all moments in time: $w_1(t) = w_2(t) = 1$.

In the manufacturing sector, each firm produces a unique product variety for supply to domestic and export markets. Competing according to Dixit and Stiglitz (1977) monopolistic competition, firms costlessly differentiate their products as they enter the market, but incur R&D costs each period, with both fixed and variable cost components. A representative firm with production located in country i employs $l_{Xi}(\omega, t)$ units of labor with the following technology:

$$x_i(\omega, t) = \theta_i(\omega, t)^\gamma l_{Xi}(\omega, t), \quad i = 1, 2, \quad (4)$$

where $x_i(\omega, t)$ is firm-level output and $\theta_i(\omega, t)$ is a firm-specific productivity coefficient.

Given the current state of its technology, each firm produces to meet the total demand from both countries. Specifically, the output of a firm with production located in country i is $x_i(\omega, t) = x_{ii}(\omega, t)L_i + \zeta x_{ij}(\omega, t)L_j$. The large mass of firms operating in the market eliminates strategic interaction between firms as they determine their optimal production levels. Thus, under monopolistic competition, each firm maximizes operating profit on sales $\pi_i(\omega, t) \equiv p_i(\omega, t)x_i(\omega, t) - l_{Xi}(\omega, t)$ by setting price equal to a constant markup over unit cost:

$$p_i(\omega, t) = \frac{1}{\sigma \theta_i(\omega, t)^\gamma}, \quad i = 1, 2. \quad (5)$$

Consequently, combining the household demands (3), production technologies (4), and pricing rules (5), we obtain the following expression for optimal operating profit:

$$\pi_i(\omega, t) = \alpha(1 - \sigma)p_i(\omega, t)^{\frac{\sigma}{\sigma-1}} \left(\frac{L_i}{P_i(t)^{\frac{\sigma}{\sigma-1}}} + \frac{\varphi T_j L_j}{P_j(t)^{\frac{\sigma}{\sigma-1}}} \right), \quad i, j = 1, 2; i \neq j, \quad (6)$$

with $\varphi \equiv \zeta^{\sigma/(\sigma-1)} \in (0, 1)$ measuring the freeness of trade; that is, $\varphi = 0$ indicates prohibitively high trade costs, $\varphi = 1$ indicates free trade, and $d\varphi/d\zeta < 0$. Similarly, the level of tariffs on goods imported into country j is indexed by $T_j \equiv (1 + \tau_j)^{1/(\sigma-1)} \in (0, 1)$ with $dT_j/d\tau_j = -T_j^{-\sigma}/(1 - \sigma) < 0$, and $T_j = 1$ for $\tau_j = 0$.

2.3 Process Innovation

At each moment in time, manufacturing firms employ labor in process innovation, raising firm value through the development of productivity improvements that lower future production costs and raise profit on sales (6). Following Smulders and Van de Klundert (1995) and Peretto (1996), the evolution of firm-level productivity for a firm with process innovation located in country i is regulated by

$$\dot{\theta}_i(\omega, t) = K_i(t)l_{R_i}(\omega, t), \quad i = 1, 2, \quad (7)$$

where $l_{R_i}(\omega, t)$ is firm-level employment in process innovation and $K_i(t)$ describes an intertemporal knowledge spillover in the R&D process.

Adapting the specification introduced by Baldwin and Forslid (2000), we model knowledge spillovers as the weighted average productivity of the technologies observable by the firm (Davis and Hashimoto, 2014):

$$K_i(t) = \frac{1}{N(t)} \left(\int_0^{N_i(t)} \theta_i(\omega, t) d\omega + \delta \int_0^{N_j(t)} \theta_j(\omega, t) d\omega \right), \quad i, j = 1, 2; i \neq j, \quad (8)$$

where $N(t) \equiv N_1(t) + N_2(t)$ is the total mass of firms. The degree of knowledge diffu-

sion is regulated by the parameter $\delta \in (0, 1)$, capturing the fact that technical knowledge tends to include both codifiable aspects that are easily transmitted across large distances and tacit aspects that can only be articulated through face-to-face communication (Keller 2004). This formulation for knowledge spillovers matches with broad empirical evidence supporting the localized nature of knowledge spillovers (Bottazzi and Peri 2003; Mancusi 2008; Thompson 2006).

Firms set their optimal employment levels in process innovation to maximize firm value $V_i(\omega, 0) \equiv \int_0^\infty e^{-\rho t} \Pi_i(\omega, t) dt$, subject to the innovation technology (7). For a firm with process innovation located in country i , total per-period profit equals operating profit on sales less the variable cost of investment in process innovation (l_{Ri}) and the fixed cost of managing innovation (l_F): $\Pi_i(\omega, t) = \pi_i(\omega, t) - l_{Ri}(\omega, t) - l_F$, where we assume that the fixed innovation cost is symmetric across countries. This optimization problem is solved using the following current value Hamiltonian function: $H_i(\omega, t) = \Pi_i(t) + c_i(\omega, t)K(t)l_{Ri}(\omega, t)$, where $c_i(\omega, t)$ describes the cost of a unit mass of new process innovations developed by a firm in country i over the time interval dt . The first order conditions for optimal investment in process innovation yield the following static and dynamic efficiency conditions:

$$c_i(t) = \frac{1}{K_i(t)}, \quad rc_i(t) - \dot{c}_i(t) = \frac{\sigma\gamma\pi_i(\omega, t)}{(1 - \sigma)c_i(t)\theta_i(\omega, t)}, \quad i = 1, 2. \quad (9)$$

Under monopolistic competition, firms ignore the effect of investment in process innovation on the price indices and knowledge spillovers, given the small market shares associated with monopolistic competition. These efficiency conditions bind when there is a positive measure of firms locating process innovation in country i .

In order to simplify the exposition, we assume that firm-level productivity is symmetric across firms, regardless of the location of production; that is, $\theta_1(t) = \theta_2(t) = \theta(t)$. As symmetric productivity levels ensure common prices and output levels for all firms,

henceforth we suppress the firm index (ω). The knowledge spillover (8) can then be simplified into two components: $K_i(t) = k_i(t)\theta(t)$, where the productivity coefficient $\theta(t)$ captures the stock of knowledge embodied in a firm's production technology. And, the regional strength of knowledge spillovers is measured by

$$k_i(t) = s_i(t) + \delta s_j(t), \quad i, j = 1, 2; i \neq j, \quad (10)$$

with $s_i(t) = N_i(t)/N(t)$ indicating the share of firms locating production in country i . Importantly, the accumulation of knowledge within the technology of each firm generates an intertemporal knowledge spillover through which current innovation efforts reduce future innovation costs. This intertemporal knowledge spillover leads to endogenous productivity growth in the long run.

2.4 Production and Innovation Location Patterns

As there are no costs incurred in shifting production or innovation between countries, firms choose the lowest cost locations for each of these activities with the aim of maximizing firm value (Martin and Rogers, 1995; Martin and Ottaviano, 1999; Davis and Hashimoto, 2023).

Beginning with the location pattern for production, firms have an incentive to shift production to the country that offers that highest per-period operating profit on sales. As such, when there is manufacturing located in both countries, the following location arbitrage condition is satisfied: $\pi_1(t) = \pi_2(t)$. Substituting the price indices (2), the pricing rule (5), and operating profit on sales (6) into the location arbitrage condition, we solve for the equilibrium share of firms locating production in country i as

$$s_i = \frac{(1 - \varphi T_i)\ell_i - (1 - \varphi T_j)\varphi T_i^\sigma}{(1 - \varphi T_i)(1 - \varphi T_j^\sigma)\ell_i + (1 - \varphi T_j)(1 - \varphi T_i^\sigma)}, \quad i, j = 1, 2; i \neq j, \quad (11)$$

where $\ell_i \equiv L_i/L_j$ captures the relative market size country i . National production

shares depend solely on model parameters and are therefore time invariant ($\dot{s}_i = 0$). Notably, an increase in relative market size (ℓ_i) raises the production share of country i through the standard home market effect (Krugman, 1980).

The effects of import tariffs on production location patterns are summarized in the following lemma.

Lemma 1 *Increasing the tariff of country i (τ_i) expands the production share of the implementing country i (s_i).*

Proof: Taking the derivative of (11) with respect to τ_i gives

$$\frac{ds_i}{d\tau_i} = -\frac{s_j(1 - \varphi T_j)\varphi\sigma T_i^{\sigma-1} + (s_j + s_i\varphi T_j^\sigma)\varphi\ell_i}{(1 - \varphi T_i)(1 - \varphi T_j^\sigma)\ell_i + (1 - \varphi T_j)(1 - \varphi T_i^\sigma)} \frac{dT_i}{d\tau_i} > 0,$$

with $ds_j/d\tau_i = -ds_i/d\tau_i$ and $dT_i/d\tau_i = -T_i^\sigma/(1 - \sigma) < 0$.

An increase in country i 's import tariff (τ_i) lowers the operating profit associated with production located in country j , inducing firms to relocate production from country j to country i until operating profit is once again equalized across countries: $\pi_1(t) = \pi_2(t)$. The effect of tariff increases on production location patterns diminishes, however, with the production share of country i converging asymptotically to $s_i = \ell_i/((1 - \varphi T_j^\sigma)\ell_i + (1 - \varphi T_j))$ as its import tariff becomes large (see Appendix A).

With operating profit equalized across countries, it is straight forward to show that all firms have the same scale of employment in production. Substituting national production shares (11) back into operating profit (6) with the price indices (2), we use the production technology (4) with the pricing rule (5) to obtain

$$l_X(t) = \frac{\alpha\sigma}{N(t)} \left(\frac{1 - \varphi^2 T_1 T_2}{1 - \varphi T_1^\sigma T_2^\sigma} \right) \left[\left(\frac{1 - \varphi T_2^\sigma}{1 - \varphi T_2} \right) L_1 + \left(\frac{1 - \varphi T_1^\sigma}{1 - \varphi T_1} \right) L_2 \right], \quad (12)$$

for all firms, regardless of the location of production. With production shares determined by relative market size (ℓ_i) and the tariffs (τ_1 and τ_2), we naturally find that the

firm-level scale of production is decreasing in the level of market entry ($N(t)$), as an increase in the total mass of firms reduces the market share of each firm.

Turning next to the location pattern for R&D, a comparison of process innovation costs ($c_i(t) = 1/(k_i\theta(t))$) indicates that firms prefer to locate innovation in the country with the strongest knowledge spillover (k_i), given that operating profits are equalized across locations. Stated differently, if $s_i > 1/2$, we have $k_i > k_j$ and $c_i < c_j$, ensuring that country i hosts all innovation activity. With all R&D located in a single country, we use the efficiency conditions (9) to obtain the following no-arbitrage condition for investment in process innovation in country i :

$$\rho \geq \frac{\sigma\gamma\pi(t)k_i}{1-\sigma} - \frac{\dot{\theta}(t)}{\theta(t)}, \quad \text{for} \quad s_i \geq 1/2, \quad i = 1, 2. \quad (13)$$

Note that the no-arbitrage condition only binds in both countries for the knife-edge case where national shares of production are equal; that is, when $s_1 = 1/2$ and $k_1 = k_2$.

2.5 Market entry

Firm value directs market entry and exit, following Novshek and Sonnenchein (1987). Specifically, the time derivative of firm value ($V(t)$) provides a no-arbitrage condition for market entry ($\rho V(t) = \Pi(t) + \dot{V}(t)$) that equates the return on investment in a new product design with the interest rate. We set the parameter condition $1 - \sigma(1 + \gamma) > 0$ to ensure that a rise in the level of market entry lower firms value.³ As a result, with no costs incurred in product development, firms enter the market when firm value is positive ($V(t) > 0$), decreasing operating profit on sales (12) and lowering firm value. And, firms exit the market when firm value is negative ($V(t) < 0$), increasing operating

³Referencing (7), (10), and (13), total per-period profit is reorganized as

$$\Pi_i(t) = \frac{(1 - \sigma(1 + \gamma))\pi(t)}{1 - \sigma} + \frac{\rho}{k_i} - l_F \quad \text{for} \quad s_i \geq 1/2, \quad i = 1, 2.$$

Then, we have $\partial\Pi_i(t)/\partial N(t) = -(1 - \sigma(1 + \gamma))\pi(t)/((1 - \sigma)N(t)) < 0$ for $1 - \sigma(1 + \gamma) > 0$.

profit and raising firm value. The adjustment process is immediate, with the total mass of firms jumping to a level that is consistent with zero per-period profit, satisfying both $V(t) = 0$ and $\dot{V}(t) = 0$ at all moments in time.

Setting per-period profits equal to zero ($\Pi(t) = 0$), we derive the free entry condition for the manufacturing industry as follows:

$$\pi(t) = l_{Ri}(t) + l_F, \quad \text{for} \quad s_i \geq 1/2, \quad i = 1, 2. \quad (14)$$

With firm value driven to zero, household wealth equals zero at all moments in time ($A_i(t) = 0$), and households only derive income from labor income and tariff revenue. Thus, in country i we have $E_i(t) = 1 + Z_i(t)$.

2.6 Tariff Revenue

National governments balance their fiscal budgets as they collect tariffs on imported goods and transfer the revenue to households in the form of lump-sum payments. Referencing the product demands (3) and the pricing rule (5), we derive the lump-sum transfer to a household residing in country i as

$$Z_i(t) = \tau_i \int_0^{N_j(t)} \zeta p_j(\omega, t) x_{ji}(\omega, t) d\omega = \frac{\alpha \varphi s_j \tau_i T_i}{s_i + \varphi s_j T_i^\sigma}, \quad i, j = 1, 2; i \neq j. \quad (15)$$

The following lemma summarizes the effects of adjustments in tariff rates on the tariff revenue of each country.

Lemma 2 *Increasing import tariff τ_i raises the tariff revenue (Z_i) of the implementing country i for $\tau_i < \tau_i^*$, and lowers Z_i for $\tau_i > \tau_i^*$, with Z_i maximized at $\tau_i = \tau_i^*$. The increase in τ_i strictly raises the tariff revenue (Z_j) of the non-implementing country j .*

Proof: See Appendix B.

In our framework, tariff revenue depends not only on the tariff rate, but also on the

location of production. Consider for example, an increase in the import tariff (τ_i) of country i . The first positive effect is the direct rise in tariff revenue resulting from a higher tariff rate on the given level of imports. The second negative effect is the fall in demand for imported product varieties that stems from higher product prices. The third negative effect is the fall in the share of imported varieties that coincides with the shift in the location of production from country j to country i , following the results of Lemma 1. In Appendix B, we show that the positive direct effect dominates for low tariff rates ($\tau_i < \tau_i^*$), but the negative indirect effects dominate for high tariff rates ($\tau_i > \tau_i^*$), generating a concave relationship between the tariff and the implementing country's tariff revenue and suggesting the existence of a tariff rate that maximizes tariff revenue (τ_i^*). For the foreign country j , the increase in country i 's tariff unambiguously raises tariff revenue (Z_j) as the mass of imported product varieties expands with the shift in the location of production from country j to country i .

3 Long-run Growth and National Welfare

We now characterize the equilibrium level of market entry, rate of productivity growth and national welfare levels. As the model jumps immediately and permanently to a balance growth path with constant values for all key macroeconomic variables, hereafter we suppress the time index t to simplify notation.

Beginning with market entry, we combine the world labor market clearing condition $L = L_1 + L_2$ with the demands for labor in agriculture and manufacturing $L_{Y1} + L_{Y2} = E_1 + E_2 - 2\alpha$ and $L_X = N(l_X + l_R + l_F)$, the no-arbitrage condition for investment in process innovation (13) and the free market entry condition (14) to obtain the total mass of firms as

$$N = \frac{(1 - \sigma(1 + \gamma))k_i}{(k_i l_F - \rho)} (\alpha L - Z_1 L_1 - Z_2 L_2) \quad \text{for} \quad s_i \geq 1/2, \quad i = 1, 2. \quad (16)$$

Given that $1 - \sigma(1 + \gamma) > 0$ is necessary for stable market entry, we find that $k_i l_F - \rho > 0$ is also required for a positive level of market entry. The following proposition outlines the effects of adjustments in tariffs on market entry.

Proposition 1 *Suppose $s_i \geq 1/2$, and all process innovation is located in country i . Increasing the tariff of country i lowers the level of market entry (N) for $\tau_i \leq \tau_i^*$, but has an ambiguous effect on N for $\tau_i > \tau_i^*$, where τ_i^* maximizes country i 's tariff revenue. Increasing in the tariff of country j generally has an ambiguous effect on N .*

Proof: See Appendix C.

Suppose that country i has a greater share of production ($s_i \geq 1/2$) and thus hosts all process innovation. An increase in the import tariff of country i (τ_i) influences market entry (N) through two channels. The first is a firm-level profit channel. Following Lemma 1, an increase in the country i tariff causes firms to shift the location of production towards country i ($ds_i/d\tau_i > 0$), improving knowledge spillovers ($dk_i/ds_i > 0$) and raising the optimal level of investment in process innovation ($dl_{Ri}/dk_i > 0$). The higher per-period cost of employment in process innovation lowers profits, however, forcing firms to exit the market, as the zero-profit scale of production rises. The second channel captures the effect of tariff adjustments on the overall profit of the manufacturing industry. For low tariff rates ($\tau_i \leq \tau_i^*$), an increase in τ_i raises the tariff revenue of both countries ($dZ_i/d\tau_i > 0$ and $dZ_j/d\tau_i > 0$), expanding household income and the world demand for the agriculture good while reducing the profit of the manufacturing industry. For high tariff rates ($\tau_i > \tau_i^*$), however, the increase in τ_i lowers the tariff revenue of country i and the overall effect on industry profit is ambiguous. Summarizing, when $\tau_i \leq \tau_i^*$, the signs of the firm-level and industry-level profit channels align, with an increase in the tariff of country i reducing the level of market entry. But, when $\tau_i > \tau_i^*$, the general effect is ambiguous.

Similarly, an increase in the tariff of country j induces a shift in the location of production towards country j ($ds_i/d\tau_j < 0$). As a result, the strength of knowledge

spillovers into the process innovation located in country i is weakened ($dk_i/ds_i > 0$), and firms reduce investment in process innovation. The subsequent decrease in the zero-profit scale of production allows for a greater level of market entry that expands the total mass of firms in the market. Although the tariff revenue of country i rises, the tariff revenue of country j may rise or fall depending on the current value of the country j 's tariff, implying an ambiguous relationship between the country j tariff and the overall profit of the manufacturing industry. Regardless, there is never a clear alignment in the signs of the firm-level and industry-level profit channels, leading to the general conclusion that the impact of an increase in the country j tariff is ambiguous.

Turning next to the equilibrium rate of productivity growth, we combine the no-arbitrage condition for investment in process innovation (13) and the free market entry condition (14) with the innovation technology (7) to obtain

$$g \equiv \frac{\dot{\theta}}{\theta} = \frac{\sigma\gamma k_i l_F - (1 - \sigma)\rho}{1 - \sigma(1 + \gamma)}, \quad \text{for} \quad s_i \geq 1/2, \quad i = 1, 2. \quad (17)$$

As $1 - \sigma(1 + \gamma) > 0$ is required for stable market entry, the above expression indicates that $k_i l_F - (1 - \sigma)\rho/(\sigma\gamma) > 0$ is necessary for a positive rate of productivity growth. In addition, we find that the long-run rate of productivity growth is scale neutral, as proportionate increases in national populations are absorbed through an expansion in the mass of firms in the market, leaving firm-level employment in process innovation unchanged. The effects of adjustments in import tariffs on the rate of productivity growth are summarized in the following proposition:

Proposition 2 *Suppose $s_i \geq 1/2$, and all process innovation is located in country i . Increasing the tariff of country i raises the long-run productivity growth rate, while increasing the tariff of country j lowers the long-run productivity growth rate.*

Proof: Taking the derivatives of (17) with respect to the tariffs yields

$$\frac{dg}{d\tau_i} = \frac{\sigma\gamma l_F}{1 - \sigma(1 + \gamma)} \frac{dk_i}{ds_i} \frac{ds_i}{d\tau_i} > 0, \quad \frac{dg}{d\tau_i} = \frac{\sigma\gamma l_F}{1 - \sigma(1 + \gamma)} \frac{dk_i}{ds_i} \frac{ds_i}{d\tau_j} < 0.$$

Suppose, once again, that country i has a greater share of production ($s_i \geq 1/2$), and therefore hosts all process innovation. From Lemma 1, an increase in the tariff of country i induces firms to shift production from country i to country j ($ds_i/d\tau_i > 0$), strengthening knowledge spillovers into the innovation process ($dk_i/ds_i > 0$). As a result, firms increase employment in process innovation, accelerating the rate of productivity growth ($dg/d\tau_i > 0$). In contrast, an increase in the tariff of county j reduces the country i share of production ($ds_i/d\tau_j < 0$), weakening knowledge spillovers ($dk_i/ds_i < 0$), and slowing the rate of productivity growth ($dg/d\tau_j < 0$).

Lastly, we investigate the effects of tariffs on social welfare. As all macroeconomic variables are constant along the balanced growth path, we combine lifetime utility (1) with household expenditure ($E_i = 1 + Z_i$) and the household demands for agricultural goods ($Y_i = E_i - \alpha$) and manufacturing goods ($X_i = \alpha/P_i$) to obtain steady-state welfare for a representative household in country i as follows:

$$U_i(0) = \hat{\alpha} + \frac{\alpha(1 - \sigma)}{\rho\sigma} \ln(s_i + s_j\varphi T_i^\sigma) N + \frac{\alpha\gamma g}{\rho^2} + \frac{Z_i}{\rho}, \quad i = 1, 2, \quad (18)$$

where $\hat{\alpha} \equiv (1 - \alpha)/\rho + (\alpha/\rho) \ln \sigma$, with initial firm-level productivity normalized to one: $\theta_1(0) = \theta_2(0) = 1$. Tariffs affect household welfare through production location patterns (s_i), market entry (N), productivity growth (g), and tariff revenue (Z_i).

To study the relationship between household utility and the tariff rate in country i ,

we take the derivative of (18) with respect to τ_i :

$$\begin{aligned} \frac{dU_i(0)}{d\tau_i} = & \frac{\alpha(\sigma\gamma(k_a l_F - \rho) + (1 - \sigma)\rho)g}{\sigma(k_a l_F - \rho)k_a \rho^2} \frac{dk_a}{d\tau_i} \\ & - \frac{\alpha(1 - \sigma)\varphi^2 T_j}{\sigma(1 - \varphi T_j)(1 - \varphi^2 T_i T_j)\rho} \frac{dT_i}{d\tau_i} + \frac{1}{\rho} \frac{dZ_i}{d\tau_i}. \end{aligned} \quad (19)$$

Consider first the case where country i has a greater share of production ($s_i \geq 1/2$) and hosts all process innovation ($k_a = k_i$). The first term on the righthand side of (19) describes a positive knowledge spillover effect ($dk_i/d\tau_i > 0$). Referencing Lemma 1, an increase in the tariff rate of country i expands country i 's share of production, strengthening knowledge spillovers. While improved knowledge spillovers have a negative effect on market entry ($dN/dk_i < 0$) and a positive effect on the rate of productivity growth ($dg/dk_i > 0$), the growth effect always dominates. The second term shows a positive price effect whereby a decrease in the share of imported product varieties lowers the average price of manufactured goods. The third term captures the revenue effect and may be positive or negative, depending on the tariff rate, as outlined in Lemma 2. Summarizing, when the tariff rate is low ($\tau_i < \tau_i^*$), the knowledge spillover, price, and revenue effects are all positive, and an increase in τ_i generates a welfare improvement in country i . Alternatively, when the tariff rate is high ($\tau_i > \tau_i^*$), the revenue effect is negative, and the welfare effect of a tariff increase is generally ambiguous. If the negative tariff revenue effect dominates for sufficiently high tariff rates, however, there will be an optimal tariff rate that maximizes country i 's welfare.

Next, we examine the case where country i has a smaller share of production ($s_i < 1/2$) and hosts no process innovation ($k_a = k_j$). In this case, while the price effect is once again positive, the knowledge spillover effect is now negative, with a shift in the location of production reducing the concentration of production in country j and weakening knowledge spillovers ($dk_j/d\tau_i < 0$). As the revenue effect is positive and large for low tariff rates, welfare improves with an increase in the tariff rate. For

high tariff rates, however, the negative knowledge spillover and revenue effects may dominate causing welfare to deteriorate with a tariff increase, suggesting the potential for an optimal tariff rate that maximizes welfare. Naturally, with an increase in the tariff rate, country i may attract a sufficient share of production to induce a shift in the location of process innovation. The welfare analysis would then proceed as described above for the case where $s_i \geq 1/2$.

To study the effects of tariff policy set by a trade partner, we take the total derivative of steady-state welfare (18) with respect to the tariff rate of country j (τ_j):

$$\begin{aligned} \frac{dU_i(0)}{d\tau_j} = & \frac{\alpha(\sigma\gamma(k_a l_F - \rho) + (1 - \sigma)\rho)g}{\sigma(k_a l_F - \rho)k_a \rho^2} \frac{dk_a}{d\tau_j} \\ & + \frac{\alpha(1 - \sigma)(1 - \varphi T_i)\varphi}{\sigma(1 - \varphi T_j)(1 - \varphi^2 T_i T_j)\rho} \frac{dT_j}{d\tau_j} + \frac{1}{\rho} \frac{dZ_i}{d\tau_j}. \end{aligned} \quad (20)$$

From this expression, we observe that if country i has a greater share of production ($s_i \geq 1/2$), and therefore hosts all process innovation ($k_a = k_i$), the knowledge spillover effect will be negative. The price effect is also negative given the expansion in the share of imported product varieties. The revenue effect is positive, however, following the results of Lemma 2. Overall, the welfare effect of an increase in tariff τ_j is ambiguous, as it depends on the balance of the negative knowledge spillover and price effects and the positive revenue effect. In contrast, if country i has a smaller share of production ($s_i < 1/2$), and hosts no process innovation ($k_a = k_j$), the knowledge spillover effect is positive, the price effect is negative, and the revenue effect is positive. Accordingly, the welfare effect of an increase in the tariff rate τ_j is once again generally ambiguous.

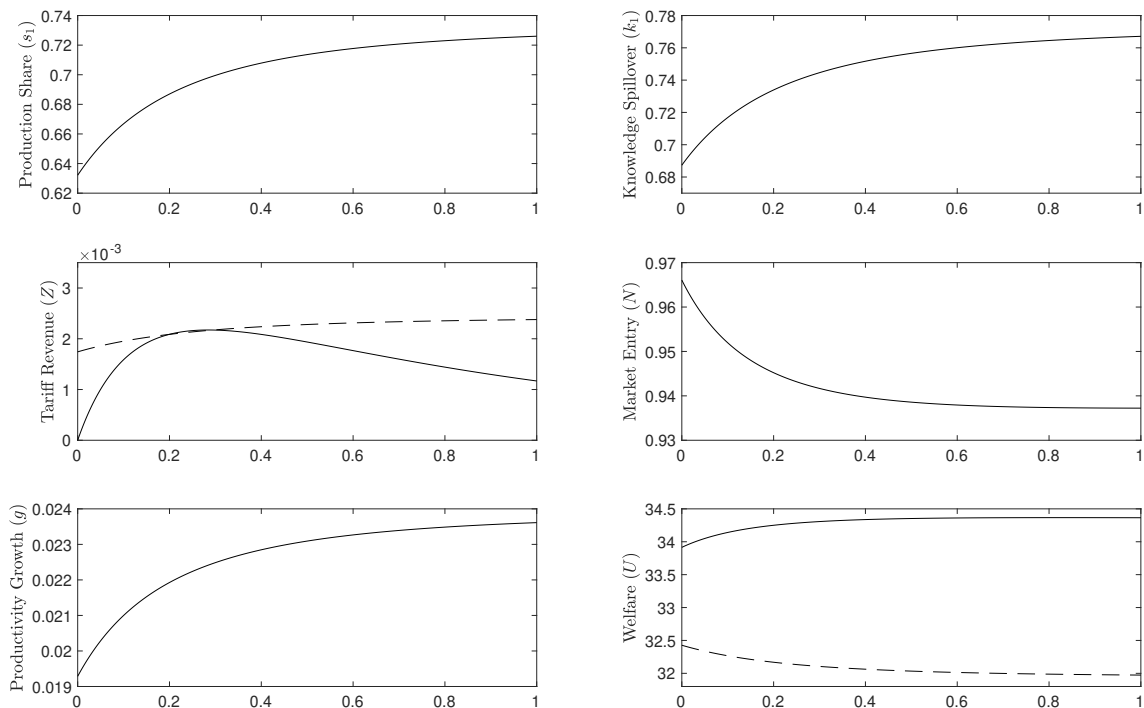
4 Numerical Evaluation

In this section, we complete simple numerical evaluations of the effects of import tariffs on national welfare. The numerical analysis is completed using the following benchmark parameters values. We set the rate of time preference to $\rho = 0.02$ following Jones et

al. (1993). The degree of product differentiation is fixed to $\sigma = 0.75$, and thus the elasticity of substitution across product varieties is $1/(1 - \sigma) = 4$, with a price-cost markup equal to 1.33, matching the estimates of De Loecker et al. (2020). Population sizes are assumed to be $L_1 = 1.5$ and $L_2 = 1$, generating a larger market size for country 1. Referencing average world tariff rates (The World Bank, 2016), the benchmark tariff rates are set to $\tau_1 = \tau_2 = 0.03$. Then, following the estimates of Anderson and van Wincoop (2004) and Novy (2013), we fix the trade cost equal to $\zeta = 1.71$ and the freeness of trade becomes $\varphi = 0.2$. A value of $\delta = 0.15$ is assumed for the degree of knowledge differentiation, matching the mid-range estimates of Bloom et al. (2013). Under these parameter assumptions, country 1's share of production is $s_1 = 0.645$ and the strength of knowledge spillovers becomes $k_1 = 0.698$. Targeting a benchmark productivity growth rate of $g = 0.02$, we fix the productivity elasticity of output to $\gamma = 0.1$ and the fixed operating cost to $l_F = 0.142$. We also assume that $\alpha = 0.25$. The benchmark parameter set yields a level of market entry equal to $N = 0.961$. The lump-sum transfers to households are $Z_1 = 0.0007$ and $Z_2 = 0.00018$. And, household utilities are $U_1 = 34$ and $U_2 = 32.37$.

In Figure 1, we present a numerical evaluation of the effects of an increase in the large country's tariff rate on production shares, knowledge spillovers, tariff revenue, market entry, productivity growth, and welfare over the policy range $\tau_1 \in (0, 1)$. Following the results of Lemma 1, an increase τ_1 expands country 1's share of production (s_1), strengthening knowledge spillovers (k_1) into innovation through a rise in the concentration of industry. As discussed in Lemma 2, in country 1 the relationship between the tariff rate and tariff revenue (Z_1) depends on the balance between the positive direct effect of a higher tariff rate and the negative effects of lower product demand and a smaller share of imported varieties. The increase in the tariff rate raises Z_1 for $\tau_1 < \tau_1^*$ and lowers Z_1 for $\tau_1 > \tau_1^*$, with tariff revenue maximized at $\tau_1^* = 0.285$. In the smaller country 2, the expansion in the share of imported varieties raises tariff revenue (Z_2).

Figure 1: Tariff Policy in the Large Country

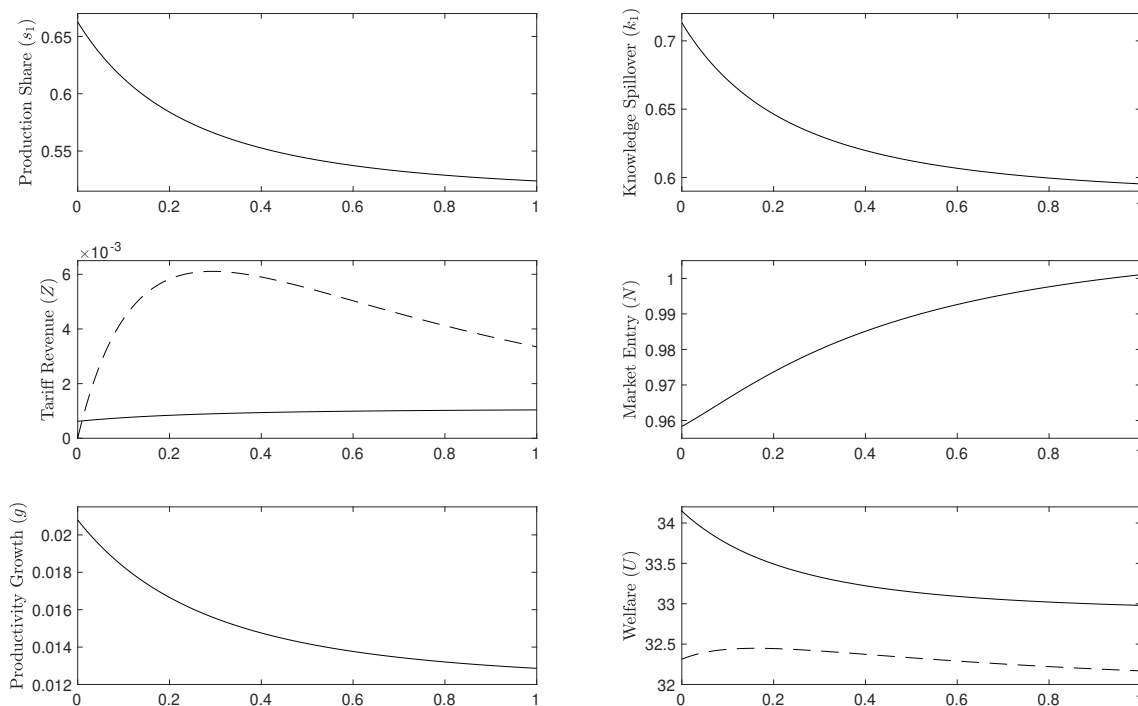


These figures are produced using the following benchmark parameter set: $\rho = 0.02$, $\alpha = 0.25$, $\sigma = 0.75$, $\gamma = 0.1$, $l_F = 0.142$, $\tau_1 = 0.03$, $\tau_2 = 0.03$, $\zeta = 1.71$, $\delta = 0.15$, $L_1 = 1.5$, $L_2 = 1$. This parameter set yields $s = 0.645$, $k = 0.698$, $N = 0.961$, $g = 0.02$, $Z_1 = 0.0007$, $Z_2 = 0.0018$, $U_1 = 34.00$, and $U_2 = 32.37$. The solid lines plot tariff revenue and welfare for country 1 and the dashed lines plot tariff revenue and welfare for country 2.

With respect to market entry (N), the effect of stronger knowledge spillovers dominates, ensuring that the mass of firms decreases over the policy range examined. Reviewing the results of Proposition 2, however, stronger knowledge spillovers also ensure a faster rate of productivity growth (g). Lastly, while the tariff increase causes a deterioration in the welfare of country 2, the welfare effect is initially positive but then turns negative for country 1. The optimal tariff rate maximizing country 1 welfare is $\tau_1 = 0.824$.

Figure 2 presents a numerical analysis of the effects of an increase in the smaller country's tariff rate on production shares, knowledge spillovers, tariff revenue, market entry, productivity growth, and welfare over the policy range $\tau_2 \in (0, 1)$. The increase in τ_2 reduces country 1's share of production (s_1), lowering the concentration of industry,

Figure 2: Tariff Policy in the Small Country



These figures are produced using the following benchmark parameter set: $\rho = 0.02$, $\alpha = 0.25$, $\sigma = 0.75$, $\gamma = 0.1$, $l_F = 0.142$, $\tau_1 = 0.03$, $\tau_2 = 0.03$, $\zeta = 1.71$, $\delta = 0.15$, $L_1 = 1.5$, $L_2 = 1$. This parameter set yields $s = 0.645$, $k = 0.698$, $N = 0.961$, $g = 0.02$, $Z_1 = 0.0007$, $Z_2 = 0.0018$, $U_1 = 34.00$, and $U_2 = 32.37$. The solid lines plot tariff revenue and welfare for country 1 and the dashed lines plot tariff revenue and welfare for country 2.

and weakening knowledge spillovers into innovation (k_1). Moreover, the expansion in the share of imported varieties raises country 1's tariff revenue (Z_1). In country 2, the tension between the positive effect of a higher tariff rate and the negative effects of lower product demand and a reduced share of imported varieties results in an inverted-U relationship between τ_2 and Z_2 . The increase in the tariff rate raises Z_2 for $\tau_2 < \tau_2^*$ and lowers Z_2 for $\tau_2 > \tau_2^*$, with tariff revenue maximized at $\tau_2^* = 0.293$. On the one hand, the increase in the tariff rate reduces the level of market entry (N), indicating that the negative effect of weaker knowledge spillovers dominates across the policy range considered. On the other hand, weaker knowledge spillovers lead to slower productivity growth (g). Finally, the increase in country 2's tariff rate lowers the welfare of country

1, but generates a positive welfare effect for low tariff rates and a negative welfare effect for high tariff rates in country 2, with an optimal tariff rate of $\tau_2 = 0.161$.

5 Conclusion

Recent years have seen an escalation in protectionist trade policies, with many countries raising import tariff rates. In this paper, we introduce a two-country model of industry location and international trade to study how national tariff policy affects productivity growth through adjustments in the geographic location of production. At the center of the framework, monopolistically competitive firms invest in process innovation to lower production costs, and independently select the lowest cost locations for production and innovation. Technical knowledge accumulates within the production technology of each firm. As locating process innovation in proximity to production improves labor productivity in innovation, international trade barriers and imperfect knowledge diffusion lead to the partial concentration of manufacturing and the full concentration of innovation in the country with the larger market, as determined by population size and import barriers. Economic growth is then linked to industry location patterns, with an increase in the geographic concentration of industry raising the rate of productivity growth.

We use the framework to examine how import tariffs influence productivity growth through adjustments in industry location patterns. On the one hand, we find that an increase in the tariff of the country with the larger market increases the geographic concentration of industry, improving knowledge spillovers into process innovation and accelerating the rate of productivity growth. On the other hand, an increase in the tariff of the country with the smaller share of manufacturing reduces the geographic concentration of industry, weakening knowledge spillovers and slowing the rate of productivity growth. We also consider the welfare effects of tariff policy and discuss the potential for optimal tariff rates.

Appendix A

In this appendix, we show that the production share of country i approaches a constant for large increases in the import tariff (τ_i). First, note that $\lim_{\tau_i \rightarrow \infty} T_i = 0$. Then, $\lim_{\tau_i \rightarrow \infty} dT_i/d\tau_i = 0$, and from (11), we have

$$s_i = \frac{\ell_i}{(1 - \varphi T_j^\sigma)\ell_i + (1 - \varphi T_j)}, \quad \frac{ds_i}{d\tau_i} = -\frac{(1 - \varphi T_j)\varphi\ell_i}{((1 - \varphi T_j^\sigma)\ell_i + (1 - \varphi T_j))^2} \frac{dT_i}{d\tau_i} = 0,$$

in the limit as τ_i approaches infinity.

Appendix B

This appendix derives the effects of changes in import tariffs on the tariff revenue of each country. We rewrite the tariff revenue of country i as

$$Z_i = \alpha\varphi(T_i^\sigma - T_i) \left(\frac{(1 - \varphi T_j) - (1 - \varphi T_i)\varphi T_j^\sigma \ell_i}{(1 - \varphi T_i)(1 - \varphi^2 T_i^\sigma T_j^\sigma)\ell_i} \right), \quad (\text{B1})$$

where we have used (11) and (15). Because $T_i = 1$ for $\tau_i = 0$, tariff revenue is naturally zero ($Z_i = 0$) when country i sets its import tariff to zero. Taking the derivative of (B1) with respect to the import tariff yields

$$\frac{dZ_i}{d\tau_i} = \varphi(1 - \varphi T_j)Z_i \left(\frac{1}{1 - \varphi T_i} + \frac{s_j\varphi\sigma T_i^{\sigma-1}T_j^\sigma}{s_j + s_i\varphi T_j^\sigma} \right) \frac{dT_i}{d\tau_i} - \frac{(1 - \sigma(1 + \tau_i))Z_i}{\tau_i T_i} \frac{dT_i}{d\tau_i}.$$

Because $dT_i/d\tau_i < 0$, the first term is strictly negative. The sign of the second term, however, depends on the tariff rate. To begin with, we note that for $\tau_i = 0$ the second term is positive and infinitely large, and thus $dZ_i/d\tau_i > 0$. Next, for $\tau_i \geq \sigma/(1 - \sigma)$, the second term is nonpositive, and consequently $dZ_i/d\tau_i < 0$. Together these points indicate the existence of a tariff rate $\tau_i^* < \sigma/(1 - \sigma)$ that maximizes tariff revenue when $s_i \in (0, 1)$ for $\tau_i = \sigma/(1 - \sigma)$. Lastly, referencing (15), we take the derivative of Z_j with

respect to τ_i to obtain

$$\frac{dZ_j}{d\tau_i} = -\frac{Z_j}{s_i(s_j + s_i\varphi T_j^\sigma)} \frac{ds_j}{d\tau_i} > 0.$$

This completes the proof of Lemma 2.

Appendix C

This appendix calculates the effects of changes in tariff rates on market entry. Taking the total derivatives of (16) with respect to the tariff rates yields:

$$\begin{aligned} \frac{dN}{d\tau_i} &= -\frac{\rho k_i N}{(k_i l_F - \rho)} \frac{dk_i}{ds_i} \frac{ds_i}{d\tau_i} - \frac{N}{(\alpha L - Z_1 L_1 - Z_2 L_2)} \left(\frac{dZ_1}{d\tau_i} L_1 + \frac{dZ_2}{d\tau_i} L_2 \right), \\ \frac{dN}{d\tau_j} &= -\frac{\rho k_i N}{(k_i l_F - \rho)} \frac{dk_i}{ds_i} \frac{ds_i}{d\tau_j} - \frac{N}{(\alpha L - Z_1 L_1 - Z_2 L_2)} \left(\frac{dZ_1}{d\tau_j} L_1 + \frac{dZ_2}{d\tau_j} L_2 \right). \end{aligned}$$

Appendix D

This appendix calculates the effects of changes in import tariffs on household utility.

First, we combine (4), (5), (6), (11), (13), and (14) to obtain

$$(s_i + s_j \varphi T_i^\sigma) N = \frac{\alpha(1 - (1 + \gamma)\sigma) k_a L_i}{(k_a l_F - \rho)} \left(\frac{1 - \varphi^2 T_i T_j}{1 - \varphi T_j} \right), \quad (\text{D1})$$

where $k_a = k_i$ for $s_i \geq 1/2$. Substituting (D1) into (18), we obtain steady-state utility for a household in country i as

$$U_i(0) = \hat{\alpha} + \frac{\alpha(1 - \sigma)}{\rho\sigma} \ln \left[\frac{\alpha(1 - (1 + \gamma)\sigma) k_i L_i}{(k_i l_F - \rho)} \left(\frac{1 - \varphi^2 T_i T_j}{1 - \varphi T_j} \right) \right] + \frac{\alpha\gamma g}{\rho^2} + \frac{Z_i}{\rho}. \quad (\text{D2})$$

The total derivatives of (D2) with respect to the import tariffs yield (19) and (20).

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