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ABSTRACT

How Trade Policy Affects Technology Adoption and Productivity*

How does trade policy affect technology adoption, total factor productivity (TFP henceforth), and *per capita* income? To study this question we construct a dynamic general equilibrium model of a small open economy in which a coalition of skilled workers decides whether or not to adopt newly available and more productive technologies. We obtain three results. First, under free trade and under a tariff the best technology is used and TFP and *per capita* income are as large as is possible. Second, under a quota the best technology may or may not be used; in both cases *per capita* income and TFP are smaller than under free trade and a tariff. Third, average growth rates are the same across all three trade policy regimes but abandoning a quota leads to a short-term increase in growth rates.

JEL Classification: E00 and E40
Keywords: quota, tariff, technology adoption, total factor productivity, and vested interest groups

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1 Introduction

This paper is motivated by several facts. First, TFP and per capita income differ greatly over time and across countries, both at the industry level and the aggregate level; see e.g. Dollar and Wolff (1993), Harrigan (1996,97), Klenov and Rodriguez-Clare (1997), and Hall and Jones (1999). A growing literature in development economics seeks to find an explanation for these differences; see Parente and Prescott (2000) and the references therein. Second, differences in the barriers to international trade are a potential candidate for explaining the differences in TFP and per capita income. For example, several recent trade policy liberalizations have been followed by strong short-term increases in the growth of TFP and per capita income. This has been documented by, among others, Kim (2000) for Korea, Ferreira and Rossi (2001) and Muendler (2001) for Brasil, Ripatti and Vilmunen (2001) for Finland, and Pavcnik (2002) for Chile.[1] Moreover, reducing quotas has been found to have different effects than reducing tariffs. Specifically Muendler (2001) estimates the positive effect on TFP of reducing by one percent a non-tariff barrier to be ten time larger than the positive effect of reducing by one percent a tariff. Finally the services and manufacturing industries of Germany, Japan, and the USA show a strong positive correlation between TFP and the degree to which domestic firms are exposed to the competition with the international productivity leaders [Baily (1993) and Baily and Gersbach (1995)]. A key factor that reduces the degree of exposure to the competition from the productivity leaders is again found to be non-tariff barriers, whereas tariffs do not affect it importantly.

Our goal in this paper is to understand theoretically how tariffs and how quotas may affect TFP and per capita income and why these effects may differ. In constructing the model economy in which we can address this question, we are guided by some additional evidence. First, Alcalá and Ciccone (2001) document that international trade affects TFP essentially through affecting the productivity of labor. We will therefore abstract from capital accumulation and borrowing and lending and assume that labor is the only factor of production. Second, there is mounting evidence that substantial parts of the observed differences in TFP and per capita income can be explained by the resistance of vested interest groups to the adoption of more productive technologies and working practices; see e.g. Mokyr (1990), McKinsey-Global-Institute (1999), and Parente and Prescott (1999,2000). Such vested interest groups may take the form of guilds, brotherhoods, professional associations, crafts unions, and the like. We will therefore put

[1]Note that some of these studies look at labor productivity instead of TFP. We abstract from this difference because the two are typically strongly positively correlated.

the activities of a vested interest group at the centre-stage of our model economy and assume that a coalition of skilled agents decides about the adoption of new technologies in its sector. Third, Rodriguez and Rodrik (1999) and Slaughter (2001), among others, have argued that there is no well established empirical relationship between trade and growth. We will therefore construct a model economy with exogenous growth, in which different trade policies leave average growth rates invariant.

Our environment has the following additional features. The model economy is small and open. There are two different sectors in which competitive firms produce two different consumption goods and one sector in which competitive firms import and export at world market prices. The first sector uses only unskilled labor, the second sector uses both unskilled and skilled labor, and the third sector uses no labor. There is exogenous technological progress. The implication for the first sector is that the marginal product of unskilled labor grows steadily. The implication for the second sector is that in each period more efficient technologies become available, which by assumption can be adopted without costs. The institutional arrangement of our model economy is such that the skilled workers form a coalition that makes the adoption decision. If they block a new and more efficient technology, then both the skilled and the unskilled of the second sector will continue using the technology they are currently using. If they adopt a new and more efficient technology, then the skilled will start using it in the next period and the unskilled will start using the technology that the skilled have been using so far.[2] The adoption decision is studied under three trade policy regimes: free trade, a tariff on the imports of the second good, and a quota on the imports of the second good.

We obtain three sets of results. First, under free trade and under a tariff the most efficient technology is used in all periods and total factor productivity and per capita income are as high as possible. Second, under a quota the most efficient technology may or may not be used in all periods; irrespective of which of the two cases applies, average total factor productivity and average per capita income are smaller under the quota than under the two other trade policies. Third, average growth rates over the whole horizon of the model economy are invariant across the three trade policy regimes, but a trade policy reform that abandons a quota increases the short–term growth rates of income and TFP.

The intuition for the first and the second result is as follows. The coalition of skilled workers will choose the technology that maximizes the indirect equilibrium utility of the representative skilled agent, which depends both on the relative price of the good the

[2]This is a reduced form that could be derived in a vintage capital model in which agents have different levels of skills that are transferable across vintages.

skilled produce and on their productivity. Under free trade or a tariff domestic firms compete with foreign firms at a relative price that is equal or proportional to the world market and is given to them. The utility of the representative skilled agent is then maximized when skilled productivity is maximized, so the coalition adopts the most efficient technology. In contrast, under a binding quota domestic firms are insulated from world market competition in excess of the quota and the link between the relative price in the home market and the world market is broken. Consequently the choice of technology now affects both the skilled productivity and the relative price of the good the skilled produce. Using in-efficient technologies increases the relative price over the world–market price but keeps productivity lower than possible. Thus, using inefficient technologies is optimal when the first effect dominates the second one. Irrespective of whether this is the case or not, a quota raises the relative price of the second good. This attracts additional unskilled workers to the second sector, who have a lower productivity there and therefore decrease average TFP and average per capita income. The intuition for our third result is as follows. The opportunity costs of blocking new technologies increase with the duration of blocking, so it is optimal to adopt the most productive technology after at most finitely many periods (and then start blocking again). As a consequence, average growth rates over the whole horizon of the model economy are invariant across different trade policies. Nevertheless, short–term growth rates increase after a quota is abandoned during a period of blocking because the best technology is adopted immediately rather than later.

Our paper is placed within the branch of the development literature that tries to explain observed differences in cross-country TFP and per capita income under the assumption that the most productive technology is a public good. Particular examples include Mankiw, Romer and Weil (1992), who emphasize the role of human capital, Chari, Kehoe and McGrattan (1996) and Parente, Rogerson and Wright (2000), who emphasize the role of public policy, Parente and Prescott (1999,2000), who emphasize the role of vested interest groups, and Acemoglu and Zilibotti (2001), who emphasize the role of skill-technology mismatch. While following the line of Parente and Prescott (1999,2000), we emphasize here the role of trade policy.

Our paper is also placed within the branch of the trade literature that studies the effects of different trade policies on technology adoption. The most closely related contributions are Holmes and Schmitz (1995) and Traca (2001). We start by discussing Holmes and Schmitz (1995), the reading of which motivated our project. Holmes and Schmitz demonstrate that the decision of vested interest groups about the adoption of newly available, more efficient technologies depends critically on whether or not there is competition in the product market from producers of other regions or states.[3] While this basic message is present also in our paper, we extend their analysis in several ways. First, they employ a static setting, and so they do not address the growth implications of different trade policies. In contrast, we study an infinite horizon model with exogenous growth, in which average growth rates are invariant across trade policy regimes but a trade policy reform can lead to short–term growth effects. Second, Holmes and Schmitz assume that skills are vintage specific, implying that the skilled agents have an incentive to block a new technology vintage so as to avoid losing their skill advantage. In contrast, in our model skills are transferable across technology vintages. Nonetheless we find that the skilled agents may want to block because it increases the relative price of the good they produce. Finally, Holmes and Schmitz study free trade and no trade, which corresponds to a zero tariff and a zero quota, whereas we consider tariffs and quotas of any size. Our finding that these two trade barriers have very different implications is at odds with the conventional wisdom that tariffs and quotas are equivalent when firms are competitive in the product market. The explanation lies in the fact that the skilled coalition has monopoly power with respect to the choice of the technology, through which it can indirectly choose the relative price of the good they produce. In that sense our result is reminiscent of Bhagwati's (1965) result that tariffs and quotas cease to be equivalent when there is a monopolist in the goods market. However, note that we need perfect competition in the goods market for our result, because a monopolist in the goods market could directly choose his output and would thus have no reason to produce inefficiently.

We continue by comparing our work with that of Traca (2001), who independently studies how trade policy affects TFP and per capita income. There are several differences between his and our work, which make the two papers complements rather than substitutes. Most importantly, Traca makes the different modeling choice of studying the effects of trade policy on R&D activities in an endogenous growth model, whereas we study the effects of trade policy on technology adoption in an exogenous growth model. Traca's modeling choice implies that he needs to allocate the monopoly power in the goods market where we have perfect competition. Traca finds that a tariff does not have an effect on the *growth rates* of TFP and per capita income whereas a quota reduces these two *growth rates*. While Traca's finding of a difference in the effects of tariffs and quotas looks as our's, it should be stressed that all our effects are *level* effects that leave

[3]In a follow–up paper, Holmes and Schmitz (2001) study the case of monopolistic producers who can allocate their time among productive and unproductive entrepreneurial activities. They identify conditions under which the reduction of trade barriers leads to a shift from unproductive to productive entrepreneurial activities.

average growth rates invariant.

The rest of the paper is organized as follows. Section 2 develops the model. Section 3 compares the equilibrium outcomes under the different trade policy regimes. Section 4 compares the results under the different trade policy regimes. Section 5 concludes the paper.

2 Environment

Time is discrete and runs forever. In each period $t \in \{0, 1, 2, ...\}$ there are five goods: two consumption goods called y_t and z_t, time l_{yt} allocated to the production of y_t, and two types of time l_{it}, $i \in \{1, 2\}$, allocated to the production of z_t. Consequently, a point x_t in the commodity space $X_t \equiv \mathbb{R}^5$ of period t is represented by $(y_t, z_t, l_{yt}, l_{1t}, l_{2t})$. The economy is assumed to be small and open in that it takes the world market prices of the two consumption goods as given. Labor is assumed to be immobile, so there is no world market for time. We normalize the world market price of y_t to one and denote the six remaining prices by p_{yt}, p_{zt}, p^*_{zt}, w_{yt}, w_{1t}, and w_{2t}, where the superscript $*$ indicates that p^*_{zt} is the world market price of z_t.

There is a continuum of finite measure of agents, who have identical preferences over sequences of commodities. These preferences are represented by the time-separable utility function $\sum_{t=0}^{\infty} \beta^t (y_t^{\alpha} z_t^{1-\alpha})^{\rho}/\rho$, where $\beta \in (0, 1)$ is the discount factor and $1 - \rho > 0$ is the coefficient of relative risk aversion. Agents differ in their endowments with productive time. Specifically, there are two types: a measure $\lambda_i > 0$, $i \in \{1, 2\}$, are type-i agents who in each period are endowed with one unit of type-i time. We think of type-1 agents as being unskilled and type-2 agents as being skilled. There is no capital in the economy and agents cannot borrow or lend. This implies that the problem of choosing consumption and working time is static. We therefore omit the time subscript from now on whenever this does not cause confusion. In order to describe the period problems, it is helpful to introduce the period consumption sets of the two types:[4]

$$X_i \equiv \{x \in X_+ : l_y + l_i \leq 1,\, l_j = 0 \text{ for } j \neq i\}. \tag{1}$$

Note that (1) implicitly assumes that the time that either type allocates to the production of y is the same good. This will be justified below when we specify the technologies. The period problem of an agent of type i is to choose from his period consumption set

[4]We use standard general equilibrium language according to which the consumption set comprises all physically feasible choices. Thus it accounts for the time constraint but not for the budget constraint.

the two consumption goods and the time allocated to the two sectors so as to maximize his period utility subject to his period budget constraint:

$$\max_{x \in X_i} y^\alpha z^{1-\alpha} \quad \text{s.t.} \quad y + p_z z \leq w_y l_y + w_i l_i. \tag{2}$$

We now turn to the production side of the economy. There are three sectors, each of which operates a constant-returns-to-scale technology and has a representative firm. Given free entry, the representative firms make zero profits, so we omit profits from now on. The available technologies of the three sectors depend on the state, which in period t is represented by $s = (a, b, t)$ with $a < b \leq t$, so the state space is $S \equiv \{(a, b, t) \in \mathbb{R}^2 \times \mathbb{N}_0 : a < b \leq t\}$. The determination of a and b will be discussed below.

The first sector produces y. Given a realization $s = (a, b, t)$ of the state in period t, the production set of its representative firm is

$$X_3(s) = \{x \in X_+ : y \leq \pi^t l_y,\ z = 0\}, \quad \pi \in (1, \infty). \tag{3a}$$

The assumption $\pi > 1$ implies that the first sector experiences exogenous technological progress. Note that both types are equally productive here, which justifies the previous assumption that the time of either type is the same good when it is allocated to the first sector. The second sector produces z. Given a realization $s = (a, b, t)$ of the state in period t, the production set of its representative firm is

$$X_4(s) = \{x \in X_+ : z \leq \gamma^a l_1 + \gamma^b l_2,\ y = 0\}, \quad \gamma \in (\pi, \infty). \tag{3b}$$

Since $a < b$ the time of type 2 (the skilled type) is more productive in sector 2 than the time of type 1 (the unskilled type). The third sector is the international trade sector. Given a realization $s = (a, b, t)$ of the state in period t, the production set of its representative firm is

$$X_5(s) = \{x \in X : y + p_z^* z = 0,\ l_y,\ l_1,\ l_2 \geq 0\}. \tag{3c}$$

This specification assumes that there is no borrowing or lending of the firms in this sector. Moreover, it assumes that there are no transportation cost.

The problems of the three representative firms are static because their choices in period t have no effects on their problems in any future period. Specifically, given a realization $s = (a, b, t)$ of the state in period t, the representative firm of sector j, $j \in \{1, 2, 3\}$, chooses from its production set the working times of both types so as to maximize its period profits:

$$\max_{x \in X_{j+2}(s)} p_y y + p_z z - w_y l_y - w_1 l_1 - w_2 l_2. \tag{4}$$

Trade takes place in sequential markets. In each period there are markets for y, z, l_y, l_1, and l_2. Using vector notation, the market clearing conditions can be written as:

$$\lambda_1 x_1(s) + \lambda_2 x_2(s) = x_3(s) + x_4(s) + x_5(s).$$

We complete the description of the environment by describing the evolution of the state. We assume that the type-2 agents form a coalition and that the institutional arrangement is such that this coalition chooses a and b so as to maximize the present value of the utility of its representative member.[5] Specifically, we assume that given a realization of the state $s = (a, b, t)$, the lowest available b' for the next period is b and the highest available b' is $t + 1$, so $b' \in [b, t + 1]$. Given the choice of b', $a' = b$ if $b' > b$ and $a' = a$ if $b' = b$. Note that at the beginning of period 0, there is no old technology. Since we are interested in deriving conditions under which the best technology is *not* adopted in all periods, we start with the best technology as the initial condition.

Assumption 1 *The initial condition is* $s = (-1, 0, 0)$.

Our specification of the law of motion means in words that if the type-2 agents choose a better technology for the next period, then the type-1 agents will gain access to the technology that the type-2 agents are currently using. If the type-2 agents choose to continue with the technology they are currently using, then the type-1 agents will also continue with the technology they are currently using. This is reminiscent of a type of vintage capital models in which agents are sorted such that new, more productive vintages are operated by the most skilled agents and old, less productive vintages are operated by less skilled agents; see for example Jovanovic (1998).

The coalition's problems of choosing the optimal technology in period t so as to maximize the utility of its representative member leads to the following dynamic programming problem:

$$v(s) = \max_{b' \in [b, t+1]} \{u(s) + \beta v(s')\} \text{ s.t. } a' = \begin{cases} b, & \text{if } b' > b \\ a, & \text{if } b' = b, \end{cases} \tag{5}$$
$$s' = (a', b', t + 1),$$

[5]Note that we have nothing to say here about how the coalition forms and how it stays together.

where $v(s)$ denotes the value of the coalition's programme and $u(s)$ denotes the period equilibrium utility of an agent of type 2, both given the state s.[6]

3 Trade Policy, Technology Adoption, and TFP

In this section, we study the economy under free trade, under a tariff on z, and under a quota on z. The latter two regimes make sense only if z is imported. We therefore restrict attention to parameter values for which z is imported in all three trade policy regimes.

3.1 Free Trade

We start our analysis with the benchmark free trade. Given the assumptions of a small open economy and of zero transportation costs, the relative prices of the two consumption goods in the home market are determined by their values in the world market, which are both exogenous to the home market: $p_y = p_y^* = 1$ and $p_z = p_z^*$.

Assumption 2 *The relative world market price of z is given by*

$$p_{zt}^* = \eta \frac{\pi^t}{\gamma^t}, \quad \eta \in (1, \gamma).$$

If the efficient technology is used this specification implies that under free trade type-1 agents (type-2 agents) work only in sector 1 (sector 2). This follows by comparing the different wages; for the details see the proof of Lemma 1 below. Focusing on this case as a benchmark is convenient but not crucial for our results.

We now define the equilibrium under free trade. For ease of exposition, we divide the definition into a static and a dynamic part. We call the former the period competitive equilibrium and the latter the recursive equilibrium. The reason why there is a period competitive equilibrium is that there is no borrowing or lending and no capital accumulation, so the choices of consumption and working time in any period have no effect on the period problems in future periods.

Definition 1 (Period Competitive Equilibrium Under Free Trade) *Given p_z^* and $s \in S$, a period competitive equilibrium under free trade are prices $\hat{p}(s) = \{\hat{p}_y(s), \hat{p}_z(s), \hat{w}_y(s), \hat{w}_1(s), \hat{w}_2(s)\}$, allocations $\{\hat{x}_i(s)\}_{i=1}^5$, and imports $\{\hat{y}^*(s), \hat{z}^*(s)\}$ such that:*[7]

[6]For the parametric class of economies considered here $u(s)$ is unique.

[7]Negative imports are exports, so we can talk about the imports of both goods.

(i) $\hat{p}_y(s) = 1$ *and* $\hat{p}_z(s) = p_z^*$*;*

(ii) $\hat{x}_i(s)$*,* $i \in \{1, 2\}$*, solves the period problem of the representative agent of type* i*;*

(iii) $\hat{x}_{j+2}(s)$*,* $j \in \{1, 2, 3\}$*, solves the period problem of the representative firm of type* j*;*

(iv) *markets clear.*

Definition 2 (Recursive Equilibrium Under Free Trade) *Given* $s = (a, b, 0)$ *and a sequence* $\{p_{zt}^*\}_{t=0}^{\infty}$*, a recursive equilibrium under free trade are price functions* $\hat{p}$*, allocation functions* $\{\hat{x}_i\}_{i=1}^5$*, import functions* $\{\hat{y}^*, \hat{z}^*\}$*, a value function* v*, and a policy function* g *such that* $\forall\, s \in S$*:*

(i) $\hat{p}(s)$*,* $\{\hat{x}_i(s)\}_{i=1}^5$*,* $\{\hat{y}^*(s), \hat{z}^*(s)\}$ *is a period competitive equilibrium with free trade;*

(ii) $v(s)$ *satisfies the functional equation (5) and* $b' = g(s)$ *is the associated optimal policy function.*

For future use we also define what we mean by blocking of the efficient technology.

Definition 3 (Blocking of the Efficient Technology) *The efficient technology is blocked in period* t *if and only if* $b < t$*.*

We start with the characterization of the period equilibrium under free trade for a given realization of the state $s \in S$. Afterwards, we will characterize the recursive equilibrium under free trade. The derivation of the period equilibrium involves five steps. First, given the form of the utility function, agents spend shares α and $1 - \alpha$ of their period incomes on the period expenditure for y and z. Second, the period problems of the representative firms, (3), imply that wages equal marginal products. Third, using this together with the solutions of the period problems of the representative agents, (2), one finds which type works in which sector. Fourth, comparing the total demands for the two goods with their total productions in the home market one finds the imports of the two goods. Finally, requiring that z be imported when both goods are produced imposes an additional restriction:[8]

Assumption 3 *The parameters are such that* $\lambda_2 \alpha \eta < \lambda_1 (1 - \alpha)$*.*

The different cases are summarized by the following lemma. The proof and the detailed characterization of the different equilibria can be found in the appendix.

[8] If only z is produced, then z must be exported.

Lemma 1 (Period-Equilibrium Under Free Trade) *Suppose that there is free trade and that Assumptions 2 and 3 hold.*

(i) If $s \in S$ is such that

$$a < b < t - \frac{\log \eta}{\log \gamma}, \tag{6a}$$

then there is a unique period equilibrium. In this equilibrium z is imported and both types work in the sector 1.

(ii) If $s \in S$ is such that

$$a < b = t - \frac{\log \eta}{\log \gamma}, \tag{6b}$$

then there is a continuum of period equilibria. In all of them z is imported and type 1 works in sector 1 whereas the allocation of type 2's time is indeterminate.[9]

(iii) If $s \in S$ is such that

$$a < t - \frac{\log \eta}{\log \gamma} < b, \tag{6c}$$

then there is a unique period equilibrium. In this equilibrium z is imported and type 1 works in sector 1 and type 2 works in sector 2.

(iv) If $s \in S$ is such that

$$a = t - \frac{\log \eta}{\log \gamma} < b, \tag{6d}$$

then there is a continuum of period equilibria. In all of them z is imported and type 2 works in sector 2 whereas the allocation of type 1's time is indeterminate.

(v) If $s \in S$ is such that

$$a > t - \frac{\log \eta}{\log \gamma}, \tag{6e}$$

then there is no period equilibrium in which z is imported.

The interpretation of this lemma is as follows. If a and b are relatively small, then all agents work in the first sector. Thus, z is not produced at all and must be imported. If a and b are in the medium range, then type-1 agents work in sector 1 (and possibly in sector 2) and type-2 agents work in sector 2 (and possibly in sector 1). In order to ensure that z is still imported, the measure of type-2 agents must be sufficiently small relative to type-1 agents (i.e. λ_2/λ_1 must be sufficiently small), the expenditure share of z must

[9] To be precise type 2's working time allocation can take on a continuum of values. Thus, it is locally not unique, or indeterminate.

be sufficiently large (i.e. α must be sufficiently small), and the relative price of z must be sufficiently small (i.e. η must be sufficiently small). These conditions are summarized by Assumption 3. If a and b become relatively large, then many or all type–1 agents work in sector 2 and z is exported.

The next order of business is to characterize the optimal choice of the technology under free trade. The key for understanding this decision lies in the fact that the relative prices are given by the world market prices, so the coalition's problem of choosing the technology that maximizes the utility of its representative member is equivalent to choosing the technology that maximizes the period income of the representative type-2 agent in equilibrium. That income equals the relative price of z times the marginal product of type 2's time allocated to sector 2.[10] Since the relative price is given the utility of the representative type-2 agent is maximized when the marginal product of type 2's time is maximized, which is achieved by choosing the highest feasible b. As a result newly available, more productive technologies are always adopted under free trade and average TFP and average per capita income are as large as possible. The next proposition formalizes this intuitive argument. To ensure that the equilibrium is stationary, we impose the standard restriction that the growth rates of the frontiers of the two sectors' technologies be not too large:

Assumption 4 *The parameters are such that* $\tilde{\beta} \equiv \beta\pi^{\alpha\rho}\gamma^{(1-\alpha)\rho} \in (0,1)$.

Proposition 1 (Recursive Equilibrium Under Free Trade) *Suppose that there is free trade and that Assumptions 1–4 hold. Then there is a unique recursive equilibrium in which z is imported and no recursive equilibrium in which z is exported. In the recursive equilibrium, type-*1 *agents work in sector* 1, *type-*2 *agents work in sector* 2, *and the most efficient technology is used in all periods.*

Proof. See the Appendix.

3.2 Tariffs

The first deviation from the benchmark free trade is a constant tariff τ on the imports of good z.[11] The tariff introduces a wedge between the relative price of z_t in the home market and the world market:

$$p_{zt} = (1+\tau)p^*_{zt}. \tag{7}$$

[10]Note that if type 2 works in both sectors this is still true because he must earn the same income in either sector. Only if type 2 works only in the first sector, this is no longer true. But this case never occurs in recursive equilibrium because type 2 can earn a higher income in sector 2.

[11]We only consider constant tariffs because we want a BGP to exist.

To take account of the tariff, the definition of the period equilibrium needs to be modified in two respects. First, one needs to recognize that p_z is now given by (7). In the statement of Definition 1, p_z^* and τ are now given and the second equation of part (i) is to be replaced by $\hat{p}_z(s) = (1+\tau)p_z^*$. Second, one needs to specify what happens with the tariff revenue that accrues because the home market price of z now exceeds the world market price. We assume that there is a government and that it collects the tariff revenue via a lump sum tax and throws it into the ocean. This is convenient but not crucial; see the discussion in Footnote 17.

The characterization of the equilibrium with a tariff proceeds in the same way as under free trade. Again we start with the period equilibrium, which can be derived following the same steps as under free trade. The results are summarized by the next lemma. The formal proof and the details of the equilibria can be found in the appendix.

Lemma 2 (Period-Equilibrium Under Tariff) *Suppose that there is a constant tariff on the imports of z and that Assumptions 2 and 3 hold.*

(i) If τ and $s \in S$ are such that

$$a < b < t - \frac{\log[\eta(1+\tau)]}{\log \gamma}, \tag{8a}$$

then there is a unique period equilibrium. In this equilibrium z is imported and both types work in the sector 1.

(ii) If τ and $s \in S$ are such that

$$a < b = t - \frac{\log[\eta(1+\tau)]}{\log \gamma}, \tag{8b}$$

then there is a continuum of period equilibria. In all of them z is imported and type 1 works in sector 1 whereas the allocation of type 2's time is indeterminate.[12]

(iii) If τ and $s \in S$ are such that

$$a < t - \frac{\log[\eta(1+\tau)]}{\log \gamma} < b < t + \frac{\log\{\lambda_1(1-\alpha)/[\lambda_2 \alpha \eta(1+\tau)]\}}{\log \gamma}, \tag{8c}$$

then there is a unique period equilibrium. In this equilibrium z is imported and type 1 works in sector 1 and type 2 works in sector 2.

[12] To be precise type 2's time allocation can take on a continuum of values. Thus, it is locally not unique, or indeterminate.

(iv) If τ and $s \in S$ are such that

$$a = t - \frac{\log[\eta(1+\tau)]}{\log\gamma} < b < t + \frac{\log\{\lambda_1(1-\alpha)/[\lambda_2\alpha\eta(1+\tau)]\}}{\log\gamma}, \tag{8d}$$

then there is a continuum of period equilibria. In all of them z is imported and type 2 works in sector 2 whereas the allocation of type 1's time is indeterminate.

(v) If τ and $s \in S$ are such that

$$a > t - \frac{\log[\eta(1+\tau)]}{\log\gamma} \quad or \quad b \geq t + \frac{\log\{\lambda_1(1-\alpha)/[\lambda_2\alpha\eta(1+\tau)]\}}{\log\gamma}, \tag{8e}$$

then there is no period equilibrium in which z is imported.

The intuition for Lemma 2 is the same as that for Lemma 1. The only new feature is that the tariff increases the relative price of z and thereby reduces the parameter space for which z is imported.

We now characterize the optimal choice of technology under a tariff. The solution to this problem turns out to be the same as under free trade, the reason being that the relative prices in the home market are still given to the coalition. Consequently, it again maximizes its utility by choosing the highest feasible b and technological progress is as large as possible. Note that this is the case although the tariff distorts the relative price of z in the home market. This distortion, however, is irrelevant for technology adoption because the coalition cannot manipulate it in its favor. As we will see below, this is different under a quota. The next proposition makes the formal statements about the recursive equilibrium. Its proof is delegated to the appendix.

Proposition 2 (Recursive Equilibrium Under Tariff) *Suppose that there is a constant tariff on the imports of z and that Assumptions 1–4 hold.*

(i) If the tariff satisfies

$$\tau < \frac{\lambda_1(1-\alpha)}{\lambda_2\alpha\eta} - 1 \quad and \quad \tau < \frac{\gamma}{\eta} - 1, \tag{9a}$$

then there is a unique recursive equilibrium in which z is imported and no recursive equilibrium in which z is exported. In the recursive equilibrium type-1 agents work in sector 1, type-2 agents work in sector 2, and the most efficient technology is used in all periods.

(ii) If the tariff satisfies

$$\tau < \frac{\lambda_1(1-\alpha)}{\lambda_2\alpha\eta} - 1 \quad \textit{and} \quad \tau = \frac{\gamma}{\eta} - 1, \tag{9b}$$

then there is a continuum of recursive equilibria in which z is imported and no recursive equilibrium in which z is exported. In all recursive equilibria type-2 agents work in sector 2, the allocation of type 1's time is indeterminate, and the most efficient technology is used in all periods.

(iii) If the tariff satisfies

$$\tau \geq \frac{\lambda_1(1-\alpha)}{\lambda_2\alpha\eta} - 1 \quad \textit{or} \quad \tau > \frac{\gamma}{\eta} - 1, \tag{9c}$$

then there is no recursive equilibrium in which z is imported.

Propositions 1 and 2 are similar, except that under a tariff the recursive equilibrium may be indeterminate or may not exist at all. The reason is that the tariff increases the relative price of z, so it may be that type–1 agents work in sector 2. Initially, the domestic economy then imports less of z and if sufficiently many type–1 agents work in sector 2 it even stops to import z. In the former case type 1's time can become indeterminate and in the latter case an equilibrium with the desired properties does not exist.

3.3 Quotas

As a second deviation from the benchmark free trade, we study a quota on the imports of z. The quota is introduced by requiring that in each period the economy imports a constant fraction Q of the total production of z, so

$$z_t^* = Qz_t, \quad Q \in [0, \infty). \tag{10}$$

It should be pointed out that the quota is assumed to grow proportionally with z. This is required for the existence of a balanced growth path, but does not crucially drive our results derived below.[13]

[13] For example, in a model version without growth and with a constant quota, similar results with respect to blocking can be obtained. Of course, statements about the growth effects of trade reform are no longer possible.

We impose two restrictions on the quota. First, we require that the quota be binding, that is, given a realization of the state s the imports that would occur with that realization of s under free trade exceed those under the quota. Second, we require that the quota increases the relative price of z above the world market price. This does not only make sense conceptually but also is consistent with the evidence; see for example Winkelmann and Winkelmann (1998).

To take account of the presence of the quota, the definition of the period equilibrium needs to be modified in two respects. First, p_z is no longer linked to p_z^* but determined in the home market. So in the statement of Definition 1, p_z^* and Q are now given and the second equation of part (i) needs to be replaced by (10). Second, like in the tariff case, we assume that the government taxes away the profits of the representative firm in the international trade sector via a lump-sum tax and throws the tax revenues into the ocean.

We again start the characterization of the equilibrium with the period equilibrium, which in principle can be derived as before, except that p_z is now determined by the equilibrium conditions of the domestic economy. The results are summarized by the following lemma. The formal proof and the details of the equilibria can be found in the appendix.

Lemma 3 (Period-Equilibrium Under Quota) *Suppose that there is a quota on the imports of good z and that Assumptions 2 and 3 hold.*

(i) If Q and $s \in S$ are such that

$$Q < \frac{\lambda_1(1-\alpha)}{\lambda_2\eta} - \alpha \quad \wedge \quad b - \frac{\log\{\lambda_1(1-\alpha)/[\lambda_2(\alpha+Q)]\}}{\log\gamma} < a < t - \frac{\log\eta}{\log\gamma}, \tag{11a}$$

then there is a unique period equilibrium such that the quota is binding and $p_z > p_z^*$. In this equilibrium type-1 agents work in both sectors and type-2 agents work in sector 2.

(ii) If Q and $s \in S$ are such that

$$Q < \frac{\lambda_1(1-\alpha)}{\lambda_2\eta} - \alpha \quad \wedge \quad a \leq b - \frac{\log\{\lambda_1(1-\alpha)/[\lambda_2(\alpha+Q)]\}}{\log\gamma}, \tag{11b}$$

then there is a unique period equilibrium such that the quota is binding and $p_z > p_z^*$. In this equilibrium type-1 agents work in sector 1 and type-2 agents work in sector 2.

(iii) If Q and $s \in S$ are such that

$$Q \geq \frac{\lambda_1(1-\alpha)}{\lambda_2} - \alpha \quad \wedge \quad b < t - \frac{\log \eta}{\log \gamma}, \tag{11c}$$

then there is a unique period equilibrium such that the quota is binding and $p_z > p_z^*$. In this equilibrium type-1 agents work in sector 1 and type-2 agents work in both sectors.

(iv) If Q and $s \in S$ are such that

$$Q < \frac{\lambda_1(1-\alpha)}{\lambda_2 \eta} - \alpha \quad \wedge \quad a \geq t - \frac{\log \eta}{\log \gamma} \tag{11d}$$

$$\text{or} \quad Q \geq \frac{\lambda_1(1-\alpha)}{\lambda_2} - \alpha \quad \wedge \quad b \geq t - \frac{\log \eta}{\log \gamma}, \tag{11e}$$

then there is no period equilibrium such that the quota is binding and $p_z > p_z^*$.

The intuition for this lemma is as follows. If the quota is relatively small and the technology in sector 2 is relatively inefficient, then the relative price of z is so high that type-1 agents work in both sectors. In this case, their production of good 2 makes up exactly for the restrictive quota on the imports of z. If the quota is in a middle range, then type-1 agents work in sector 1, type-2 agents work in sector 2, and the relative price of z adjusts to equalize the demand for z with the production plus the imports of z, the latter being equal to the binding quota. If the quota becomes relatively large but the technology in sector 2 is not too efficient, then the relative price of z falls by so much that type-2 agents start to work in sector 1. The reduction in the production of z is in this case offset by the imports. If the quota becomes relatively large and the technology in sector 2 is relatively efficient, then there is no period-equilibrium with the desired properties, that is, the quota binds and the relative price of z in the home market exceeds that in the world market. The reason is that either the relative price of z falls below the world market price or the quota stops to bind.[14]

The next order of business is to characterize the optimal choice of the technology under the quota. The key difference to the previous two cases is that the relative prices are no longer given by the world market prices. Consequently the coalition's problem of maximizing the utility of its representative member is no longer equivalent to maximizing

[14]Note that the presence of the quota excludes the possibility that the equilibrium time allocation of one of the two type's is indeterminate. The explanation is that the quota pins down the imports and thereby also the quantities of the two outputs. Thus, the time allocation of the type that is indifferent between the two sectors becomes determinate.

the marginal product of type-2 labor. Instead the coalition's choice of technology now affects both the marginal product of type-2 time and the relative price of z. It turns out that choosing an inefficient technology may lead to an increase in the relative price of z that is large enough to outweigh the decrease in the marginal product in utility terms. In these cases, it is beneficial for the coalition to block. The next proposition formalizes this argument. Its proof can again be found in the appendix.

Proposition 3 (Recursive Equilibrium Under Quota) *Suppose that there is a quota on the imports of good z and that Assumptions 1–4 hold.*

(i) If the quota is such that

$$Q < \frac{\lambda_1(1-\alpha)}{\lambda_2\eta} - \alpha, \tag{12a}$$

then there is a recursive equilibrium such that the quota is binding and $p_z > p_z^*$ in all periods. There are two possibilities.

1. *Type-1 agents work in sector 1 and possibly also in sector 2, type-2 agents work in sector 2, and the most efficient technology is blocked for at least one and at most a finite and bounded number of periods; if α is sufficiently large, then every equilibrium has these properties.*
2. *Type-1 agents work in both sectors, type-2 agents work in sector 2, and the most efficient technology is used in all periods; if α is sufficiently small, then every equilibrium has these properties.*

(ii) If the quota satisfies

$$Q \geq \frac{\lambda_1(1-\alpha)}{\lambda_2\eta} - \alpha, \tag{12b}$$

then there is no recursive equilibrium such that the quota is binding and $p_z > p_z^*$ in all periods.

It is important to realize that blocking can occur in recursive equilibrium although the costs of adopting the new technology are nil. Specifically, condition (12a) shows that a necessary condition for blocking is that the quota Q is relatively small compared to the expenditure share of the second good and the measure λ_2 of the skilled is relatively small compared to the measure λ_1 of the unskilled. The interpretation is that these conditions make it relatively easy to increase the relative price of z through blocking. However, it is not clear whether the coalition will indeed find it optimal to block when (12a) holds. The reason is that blocking not only increases their income but also their expenditure on z. Thus, they only choose to block when the expenditure share $1-\alpha$ of z is relatively small.

The reason for blocking the most efficient technology is that adopting it reduces the relative price of z, which reduces the welfare of the skilled agents while increasing aggregate welfare (and thus the welfare of the unskilled agents). This is similar to the effect of immiserizing growth, which can occur in a large open economy with a distortion. In this case growth decreases the welfare of the economy experiencing it due to the resulting detrimental terms–of–trade effect, while the welfare of the world economy increases; see Bhagwati, Panagariya and Srinivasan (1998) for a textbook discussion.

4 Comparisons Across Trade Policy Regimes

We start by comparing the properties of the different equilibria. Specifically, we are interested in aggregate TFP, aggregate per capita income, and average growth rates. Evaluating aggregate TFP and aggregate per capita income in international prices and taking as given that in equilibrium type-2 agents work only in sector 2, we find that aggregate TFP and aggregate per capita income are the same in our economy and are given by:

$$\frac{\lambda_1 l_{yt}}{\lambda_1+\lambda_2}\pi^t + \frac{\lambda_1 l_{1t}}{\lambda_1+\lambda_2}\eta\pi^t\gamma^{a-t} + \frac{\lambda_2}{\lambda_1+\lambda_2}\eta\pi^t\gamma^{b-t}.$$

The next proposition states the results of the comparison. Its proof can be found in the appendix.

Proposition 4 (TFP, Per Income, and Growth Rates Across Regimes) *Suppose that Assumptions 1–4 hold. Then the following is true generically: average growth rates are equal across all three regimes and aggregate TFP and aggregate per capita income are equal under free trade and the tariff and smaller under the quota, except in the initial period.*[15]

It is important to stress that our model predicts differences in TFP and per capita income between free trade/tariffs and a quota irrespective of whether there is blocking under the quota. In other words, TFP and per capita income under the quota are smaller even if the recursive equilibrium is such that the most efficient technology is always adopted. The reason is that the quota increases the relative price of z, which increases the measure of type–1 workers in the second sector. Since in international prices type–1 agents are

[15]Generically means for all parameters with the possible exception of a set of parameters of zero measure.

more productive in the first sector than in the second sector, TFP and per capita income in the second sector are smaller under a quota.

Proposition 4 shows that the standard equivalence between tariffs and quotas with competitive firms does not hold in our model.[16] The reason is that the skilled workers have sufficient monopoly power. A quota then limits foreign competition and allows them to manipulate the domestic relative price of z in its favor. This is reminiscent of Bhagwati's non-equivalence result between tariffs and quotas when there is a monopolist in the goods market. Note, however, that it is crucial for our result that here the monopoly power is allocated in the factor market. The reason is that in our framework a monopolist in the goods market would have no reason to block efficient technologies because he could choose the relative price of his good through restricting output directly.

Our model predicts that the *average* growth rates of TFP and per capita income are invariant across the different trade policy regimes considered. As argued in the introduction, this feature of our results is consistent with the view advocated e.g. by Rodriguez and Rodrik (1999) and Slaughter (2001) that there is no well established empirical relationship between openness and growth. There is also evidence, however, that a trade liberalization can increase short–term growth of TFP and per capita income; see Kim (2000) for Korea, Ferreira and Rossi (2001) and Muendler (2001) for Brasil, Ripatti and Vilmunen (2001) for Finland, and Pavcnik (2002) for Chile. This is consistent with the predictions that *average* growth rates are invariant. To see why suppose that for a number of periods there is blocking of new technologies and thus no growth of TFP or per capita income. Suppose further that in one of these periods the quota is replaced by free trade or a tariff. Our model predicts that the coalition will immediately adopt the most efficient technology, implying that TFP and per capita income will immediately jump to the frontier and grow steadily thereafter. Consequently if one observes our model economy for a limited number of periods before and after the change in policy, one will conclude that a trade liberalization affects positively growth, albeit the average growth rate over the whole (infinite) horizon of the model economy remains the same.

We complete the comparison by evaluating the welfare of the two types under the different trade policy regimes. We measure a type's welfare by his present discounted equilibrium utilities. Comparing these leads to the next proposition, which is proved in the appendix.[17]

[16] See for example see Bhagwati et al. (1998) for a textbook discussion of this equivalence result.

[17] It should be pointed out that our welfare analysis is valid despite the assumption that lump sum tax proceeds are not redistributed but thrown into the ocean. The reason is that both a tariff and a quota reduce aggregate welfare in our economy. Given that they are found to increase the welfare of the skilled agents, they would decrease the welfare of the unskilled even if they received all the tax proceeds

Proposition 5 (Welfare Across Regimes) *Suppose that Assumptions 1–4 hold. Then the following is true generically:*

*(i) type-*1 *agents prefer free trade over both other trade policies; if and only if the tariff is sufficiently small they prefer the tariff over the quota; they become indifferent as* α *converges to* 1*;*

*(ii) type-*2 *agents prefer both other trade policies over free trade; if and only if the tariff is sufficiently large they prefer the tariff over the quota; they become indifferent as* α *converges to* 0.

This proposition shows that the unskilled and the skilled have opposite interests. While our framework has nothing to say about which trade policy regime will emerge, it is interesting to observe that the differences in the utility terms of the unskilled agents become arbitrarily small as the expenditure share of the second good goes to zero. The classic argument of Olson (1982) then applies: A well organized interest group is likely to succeed at imposing inefficiencies on society when the resulting benefits to it are large and the resulting costs to society are small. Specifically, this argument implies that trade barriers will be erected if α is sufficiently large; see Bridgeman, Livshits and MacGee (2001) for a model of lobbying and technology adoption.

5 Conclusion

We have constructed a dynamic general equilibrium model of a small open economy, in which a coalition of skilled workers decides whether new, and more productive, technologies are adopted. We have derived three main results. First, under free trade or a tariff, the best technology is used in all periods, implying that total factor productivity and per capita income are as large as possible. Second, under a quota, the best technology may be blocked for intervals of finitely many periods during which industry TFP and industry per capita income stagnate; irrespective of whether or not there is blocking, aggregate total factor productivity and aggregate per capita income fall short of their values under free trade and the tariff. Third, average growth rates of TFP and per capita income are invariant across trade policy regimes, but short–term growth rates may increase after a quota is abandoned.

Our results offer an explanation for the empirical findings of Baily (1993) and Baily and Gersbach (1995) that exposure to the competition from the productivity leaders is

from the profits of the importing firms.

strongly positively correlated with the levels of TFP and per capita income. They also offer an explanation for the finding of Muendler (2001) that during Brasil's recent trade policy reform the positive effect on productivity of reducing non-tariff barriers is estimated to be ten time larger than the positive effect of reducing tariffs. Moreover, our results are consistent with the evidence reported by Rodriguez and Rodrik (1999) and Slaughter (2001) that there is no well-established link between trade and growth.

We conclude by pointing to some directions for future research. First, more empirical evidence on the specific effects of tariffs and quotas on TFP is desirable to supplement the findings of Baily (1993) and Baily and Gersbach (1995) and of Muendler (2001). Second, while the present paper has studied the effects of trade policy qualitatively, it would be interesting to calibrate a dynamic general equilibrium model in order to assess the quantitative implications of different trade policies for TFP and per capita income.

Appendix

Proof of Lemma 1. For the derivation of the different equilibria it is essential to clarify where the two types work. To find this out, solve the firms' problems which gives the different wages (expressed in units of the numeraire y):

$$w_{yt} = \pi^t, \quad w_{1t} = \eta\pi^t\gamma^{a-t}, \quad w_{2t} = \eta\pi^t\gamma^{b-t}. \tag{13}$$

Case (i) comes about as follows. If and only if (6a) holds, then $w_{1t} < w_{2t} < w_{yt}$. In this case, both types work in sector 1. Specifically:

$$\hat{p}\ (s) = \{1, \eta\pi^t\gamma^{-t}, \pi^t, \eta\pi^t\gamma^{a-t}, \eta\pi^t\gamma^{b-t}\}, \tag{14}$$

$$\begin{aligned}
\hat{x}_1(s) &= \{\alpha\pi^t, (1-\alpha)\gamma^t\eta^{-1}, 1, 0, 0\},\\
\hat{x}_2(s) &= \{\alpha\pi^t, (1-\alpha)\gamma^t\eta^{-1}, 1, 0, 0\},\\
\hat{x}_3(s) &= \{(\lambda_1+\lambda_2)\pi^t, 0, \lambda_1+\lambda_2, 0, 0\},\\
\hat{x}_4(s) &= \{0, 0, 0, 0, 0\},\\
\hat{x}_5(s) &= \{-(\lambda_1+\lambda_2)(1-\alpha)\pi^t, (\lambda_1+\lambda_2)(1-\alpha)\gamma^t\eta^{-1}, 0, 0, 0\}.
\end{aligned} \tag{15}$$

Since z is not produced it must be imported, so no additional restriction arises.

Case (ii) comes about as follows. If and only if (6b) holds, then $w_{1t} < w_{2t} = w_{yt}$. Note that the equality implies that $\gamma^b = \gamma^t\eta^{-1}$. In this case, type 1 works in sector 1 and type 2 is indifferent between the two sectors. Specifically:

$$
\begin{aligned}
\hat{p}\ (s) &= \{1, \eta\pi^t\gamma^{-t}, \pi^t, \eta\pi^t\gamma^{a-t}, \pi^t\},\\
\hat{x}_1(s) &= \{\alpha\pi^t, (1-\alpha)\gamma^t\eta^{-1}, 1, 0, 0\},\\
\hat{x}_2(s) &= \{\alpha\pi^t, (1-\alpha)\gamma^t\eta^{-1}, \iota, 0, 1-\iota\}, \quad \iota \in [0,1],\\
\hat{x}_3(s) &= \{(\lambda_1+\lambda_2\iota)\pi^t, 0, \lambda_1+\lambda_2\iota, 0, 0\},\\
\hat{x}_4(s) &= \{0, \lambda_2(1-\iota)\gamma^b, 0, 0, \lambda_2(1-\iota)\},\\
\hat{x}_5(s) &= \{-[\lambda_1(1-\alpha)+\lambda_2(\iota-\alpha)]\pi^t, [\lambda_1(1-\alpha)+\lambda_2(\iota-\alpha)]\gamma^t\eta^{-1}, 0, 0, 0\}.
\end{aligned}
\tag{16}
$$

The additional requirement that z be imported is satisfied if and only if $\iota > \alpha - \lambda_1\lambda_2^{-1}(1-\alpha)$. The assumption that $\eta \in (1,\gamma)$ and Assumption 3 imply that the right-hand side is negative, so z is imported for all $\iota \in [0,1]$ and no additional restriction arises.

Case (iii) comes about as follows. If and only if (6c) holds, then $w_{1t} < w_{yt} < w_{2t}$. In this case, type 1 works in sector 1 and type 2 works in sector 2. Specifically:

$$
\begin{aligned}
\hat{p}\ (s) &= \{1, \eta\pi^t\gamma^{-t}, \pi^t, \eta\pi^t\gamma^{a-t}, \eta\pi^t\gamma^{b-t}\},\\
\hat{x}_1(s) &= \{\alpha\pi^t, (1-\alpha)\gamma^t\eta^{-1}, 1, 0, 0\},\\
\hat{x}_2(s) &= \{\alpha\eta\pi^t\gamma^{b-t}, (1-\alpha)\gamma^b, 0, 0, 1\},\\
\hat{x}_3(s) &= \{\lambda_1\pi^t, 0, \lambda_1, 0, 0\},\\
\hat{x}_4(s) &= \{0, \lambda_2\gamma^b, 0, 0, \lambda_2\},\\
\hat{x}_5(s) &= \{-\lambda_1(1-\alpha)\pi^t + \lambda_2\alpha\eta\pi^t\gamma^{b-t}, \lambda_1(1-\alpha)\gamma^t\eta^{-1} - \lambda_2\alpha\gamma^b, 0, 0, 0\}.
\end{aligned}
\tag{17}
$$

The additional restriction that z be imported leads to

$$0 < \frac{\lambda_1(1-\alpha)\gamma^{t-b}}{\lambda_2\alpha\eta} - 1,$$

which is ensured by Assumption 3 together with $\gamma > 1$.

Case (iv) comes about as follows. If and only if (6d) holds, then $w_{yt} = w_{1t} < w_{2t}$. Note that the equality implies that $\gamma^a = \gamma^t\eta^{-1}$. In this case, type 2 works in sector 2 and type 1 is indifferent between working in either sector. Specifically:

$$\begin{aligned}
\hat{p}\ (s) &= \{1, \eta\pi^t\gamma^{-t}, \pi^t, \pi^t, \eta\pi^t\gamma^{b-t}\},\\
\hat{x}_1(s) &= \{\alpha\pi^t, (1-\alpha)\gamma^t\eta^{-1}, \iota, 1-\iota, 0\}, \quad \iota \in (0,1],\\
\hat{x}_2(s) &= \{\alpha\eta\pi^t\gamma^{b-t}, (1-\alpha)\gamma^b, 0, 0, 1\},\\
\hat{x}_3(s) &= \{\lambda_1\iota\pi^t, 0, \lambda_1\iota, 0, 0\},\\
\hat{x}_4(s) &= \{0, \lambda_1(1-\iota)\gamma^a + \lambda_2\gamma^b, \lambda_1(1-\iota), 0, \lambda_2\},\\
\hat{x}_5(s) &= \{-\lambda_1(\iota-\alpha)\pi^t + \lambda_2\alpha\eta\pi^t\gamma^{b-t}, \lambda_1(\iota-\alpha)\gamma^t\eta^{-1} - \lambda_2\alpha\gamma^b, 0, 0, 0\}.
\end{aligned}$$

Using that $\gamma^a = \gamma^t\eta^{-1}$, the additional requirement that z be imported leads to

$$\iota > \alpha + \lambda_1^{-1}\lambda_2\alpha\gamma^{b-a}.$$

Given Assumption 3, the right-hand side is smaller than 1, so $\iota \in (\alpha + \lambda_1^{-1}\lambda_2\alpha\gamma^{b-a}, 1]$.

We complete the proof with case (v). If we are not in cases (i)–(iv), z is exported because there is too little production of y to export it. The conditions in (6e) follow by logically negating (6c) and (6d). ∎

Proof of Proposition 1. We start the proof by transforming the coalition's dynamic programming problem into an equivalent stationary problem. To this end, we make the following change of variables:

$$\tilde{y}_t \equiv \frac{y_t}{\pi^t}, \ \ \tilde{y}_{it} \equiv \frac{y_{it}}{\pi^t}, \quad \tilde{y}_t^* \equiv \frac{y_t^*}{\pi^t}, \quad \tilde{z}_t \equiv \frac{z_t}{\gamma^t}, \ \ \tilde{z}_{it} \equiv \frac{z_{it}}{\gamma^t}, \quad \tilde{z}_t^* \equiv \frac{z_t^*}{\gamma^t}. \tag{18}$$

Now rewrite the present discounted value of type-2's utility in terms of these stationary variables:

$$\sum_{t=0}^{\infty}\beta^t\frac{(y_{2t}^{\alpha}\, z_{2t}^{1-\alpha})^{\rho}}{\rho} = \sum_{t=0}^{\infty}\tilde{\beta}^t\frac{(\tilde{y}_{2t}^{\alpha}\, \tilde{z}_{2t}^{1-\alpha})^{\rho}}{\rho}. \tag{19}$$

where $\tilde{\beta} \equiv \beta\pi^{\alpha\rho}\gamma^{(1-\alpha)\rho}$.[18] Finally, define $\tilde{b} \equiv b - t$, $\tilde{a} \equiv a - t$, $\tilde{t} \equiv t - t = 0$, $\tilde{s} \equiv (\tilde{a}, \tilde{b}, \tilde{t})$. Given that $b' \in [b, t+1]$, we have $\tilde{b}' \in [\tilde{b}, 1]$, so we can write the dynamic programming problem as:

$$\tilde{v}(\tilde{s}) = \max_{\tilde{b}'\in[\tilde{b},1]}\{\tilde{u}(\tilde{s}) + \tilde{\beta}\tilde{v}(\tilde{s}')\} \ \text{ s.t. } \ \tilde{a}' = \begin{cases} \tilde{b}, & \text{if } \tilde{b}' > \tilde{b}\\ \tilde{a}, & \text{if } \tilde{b}' = \tilde{b}, \end{cases} \qquad \tilde{s}' = (\tilde{a}', \tilde{b}', \tilde{t}'), \tag{20}$$

[18]Note that Assumption 4 ensures that $\tilde{\beta} \in (0,1)$.

where

$$\tilde{u}(\tilde{s}_t) \equiv \frac{[\tilde{y}(\tilde{s}_t)^{\alpha}\tilde{z}(\tilde{s}_t)^{1-\alpha}]^{\rho}}{\rho}, \quad \tilde{y}(\tilde{s}_t) \equiv \frac{y[\tilde{s}_t + (t,t,t)]}{\pi^t}, \quad \tilde{z}(\tilde{s}_t) \equiv \frac{z[\tilde{s}_t + (t,t,t)]}{\gamma^t}. \tag{21}$$

Now, guess that the value function to problem (20) is given by:[19]

$$\tilde{v}(\tilde{a},\tilde{b},\tilde{t}) = \begin{cases} \frac{(\alpha\eta)^{\alpha\rho}(1-\alpha)^{(1-\alpha)\rho}}{\rho\eta^{\rho}} + \frac{\tilde{\beta}(\alpha\eta)^{\alpha\rho}(1-\alpha)^{(1-\alpha)\rho}}{\rho(1-\tilde{\beta})}, & \text{if } \tilde{a} < \tilde{b} \leq -\frac{\log\eta}{\log\gamma}, \\ \frac{(\alpha\eta\gamma^{\tilde{b}})^{\alpha\rho}(1-\alpha)^{(1-\alpha)\rho}}{\rho} + \frac{\tilde{\beta}(\alpha\eta)^{\alpha\rho}(1-\alpha)^{(1-\alpha)\rho}}{\rho(1-\tilde{\beta})}, & \text{if } \tilde{a} \leq -\frac{\log\eta}{\log\gamma} < \tilde{b} \leq 0. \end{cases}$$

It is straightforward to demonstrate that indeed this guess satisfies the functional equation (20), implying that it is a value function to (20). The form of the value function implies that the value of the programme is maximized when $\tilde{b}$ is maximized. Thus, $\tilde{b} = 0$, $\tilde{g}(\tilde{s}) = (-1, 0, 0)$, and the most efficient technology is always chosen.

It remains to be shown that the value function is unique. This follows from Theorem 4.6 of Stokey and Lucas with Prescott (1989). To see this, we need to define several objects. First, given that the most efficient technology is always chosen, we set $\mathcal{X} \equiv [0,1]$ and define $\Gamma : \mathcal{X} \to [0,1]$ by $\Gamma(\tilde{b}) = [\tilde{b}, 1]$; Γ thus defined is nonempty, compact-valued, and continuous. Second, define the set $A \equiv \{(\tilde{b}, \tilde{b}') \in \mathcal{X}^2 : \tilde{b}' \in \Gamma(\tilde{b})\}$. Third, define $F : A \to \mathbb{R}_+$, where $F(\tilde{b}, \tilde{b}') \equiv \frac{(\alpha\eta\gamma^{\tilde{b}})^{\alpha\rho}(1-\alpha)^{(1-\alpha)\rho}}{\rho}$; trivially F thus defined is continuous and bounded. So all assumptions of Theorem 4.6 are satisfied and it follows that there exists a unique value function $\tilde{v}(\tilde{s})$. This completes the proof. ■

Proof of Lemma 2. The proof follows similar steps as that of Lemma 1. The main difference is that η is to be replaced by $(1+\tau)\eta$. The wages (expressed in units of the numeraire y) are now:

$$w_{yt} = \pi^t, \quad w_{1t} = (1+\tau)\eta\pi^t\gamma^{a-t}, \quad w_{2t} = (1+\tau)\eta\pi^t\gamma^{b-t}. \tag{22}$$

To begin with, case (i) comes about as follows. If and only if (8a) holds, then

[19] This guess can be obtained as follows. Using Lemma 1, compute the utility for the current period for each $\tilde{s}$. Then assume that from the next period onwards the most efficient technology is used and utilize Lemma 1 to compute the continuation utility. Note that given the initial condition $s = (-1, 0, 0)$, case (v) of Lemma 1 cannot apply.

$w_{1t} < w_{2t} < w_{yt}$. In this case, both types work in sector 1. Specifically:

$$\begin{aligned}
\hat{p}\ (s) &= \{1, (1+\tau)\eta\pi^t\gamma^{-t}, \pi^t, (1+\tau)\eta\pi^t\gamma^{a-t}, (1+\tau)\eta\pi^t\gamma^{b-t}\}, \\
\hat{x}_1(s) &= \{\alpha\pi^t, (1-\alpha)\gamma^t[(1+\tau)\eta]^{-1}, 1, 0, 0\}, \\
\hat{x}_2(s) &= \{\alpha\pi^t, (1-\alpha)\gamma^t[(1+\tau)\eta]^{-1}, 1, 0, 0\}, \\
\hat{x}_3(s) &= \{(\lambda_1+\lambda_2)\pi^t, 0, \lambda_1+\lambda_2, 0, 0\}, \\
\hat{x}_4(s) &= \{0, 0, 0, 0, 0\}, \\
\hat{x}_5(s) &= \{-(\lambda_1+\lambda_2)(1-\alpha)\pi^t, (\lambda_1+\lambda_2)(1-\alpha)\gamma^t[(1+\tau)\eta]^{-1}, 0, 0, 0\}.
\end{aligned} \tag{23}$$

Since z is not produced it must be imported and there is no additional restriction.

Case (ii) comes about as follows. If and only if (8b) holds, then $w_{1t} < w_{2t} = w_{yt}$. Note that the equality implies that $\gamma^b = \gamma^t[(1+\tau)\eta]^{-1}$. In this case, type 1 works in sector 1 and type 2 is indifferent between the two sectors. Specifically:

$$\begin{aligned}
\hat{p}\ (s) &= \{1, (1+\tau)\eta\pi^t\gamma^{-t}, \pi^t, (1+\tau)\eta\pi^t\gamma^{a-t}, \pi^t\}, \\
\hat{x}_1(s) &= \{\alpha\pi^t, (1-\alpha)\gamma^t[(1+\tau)\eta]^{-1}, 1, 0, 0\}, \\
\hat{x}_2(s) &= \{\alpha\pi^t, (1-\alpha)\gamma^t[(1+\tau)\eta]^{-1}, \iota, 0, 1-\iota\}, \quad \iota \in [0,1], \\
\hat{x}_3(s) &= \{(\lambda_1+\lambda_2\iota)\pi^t, 0, \lambda_1+\lambda_2\iota, 0, 0\}, \\
\hat{x}_4(s) &= \{0, \lambda_2(1-\iota)\gamma^b, 0, 0, \lambda_2(1-\iota)\}, \\
\hat{x}_5(s) &= \{-[\lambda_1(1-\alpha)+\lambda_2(\iota-\alpha)]\pi^t, [\lambda_1(1-\alpha)+\lambda_2(\iota-\alpha)]\gamma^t[(1+\tau)\eta]^{-1}, 0, 0, 0\}.
\end{aligned} \tag{24}$$

The additional requirement that z be imported leads to the restriction $\iota > \alpha - \lambda_1\lambda_2^{-1}(1-\alpha)$. The assumption that $\eta \in (1, \gamma)$ and Assumption 3 imply that the right-hand side is negative, so z is imported for all $\iota \in [0,1]$.

Case (iii) comes about as follows. If and only if the first two inequalities in (8c) hold, then $w_{1t} < w_{yt} < w_{2t}$. In this case, type 1 works in sector 1 and type 2 works in sector 2. Specifically:

$$\begin{aligned}
\hat{p}\ (s) &= \{1, (1+\tau)\eta\pi^t\gamma^{-t}, \pi^t, (1+\tau)\eta\pi^t\gamma^{a-t}, (1+\tau)\eta\pi^t\gamma^{b-t}\}, \\
\hat{x}_1(s) &= \{\alpha\pi^t, (1-\alpha)\gamma^t[(1+\tau)\eta]^{-1}, 1, 0, 0\}, \\
\hat{x}_2(s) &= \{\alpha(1+\tau)\eta\pi^t\gamma^{b-t}, (1-\alpha)\gamma^b, 0, 0, 1\}, \\
\hat{x}_3(s) &= \{\lambda_1\pi^t, 0, \lambda_1, 0, 0\}, \\
\hat{x}_4(s) &= \{0, \lambda_2\gamma^b, 0, 0, \lambda_2\}, \\
\hat{x}_5(s) &= \{-\lambda_1(1-\alpha)\pi^t + \lambda_2\alpha(1+\tau)\eta\pi^t\gamma^{b-t}, \lambda_1(1-\alpha)\gamma^t[(1+\tau)\eta]^{-1} - \lambda_2\alpha\gamma^b, 0, 0, 0\}.
\end{aligned} \tag{25}$$

The additional restriction that z be imported leads to

$$\tau < \frac{\lambda_1(1-\alpha)\gamma^{t-b}}{\lambda_2\alpha\eta} - 1,$$

which is equivalent to the third inequality in (8c).

Case (iv) comes about as follows. If and only if the first two parts of (8d) hold, then $w_{yt} = w_{1t} < w_{2t}$. Note that the equality implies that $\gamma^a = \gamma^t[(1+\tau)\eta]^{-1}$. In this case, type 2 works in sector 2 and type 1 is indifferent between working in either sector. Specifically:

$$\begin{aligned}
&\hat{p}\ (s) = \{1, (1+\tau)\eta\pi^t\gamma^{-t}, \pi^t, \pi^t, (1+\tau)\eta\pi^t\gamma^{b-t}\},\\
&\hat{x}_1(s) = \{\alpha\pi^t, (1-\alpha)\gamma^t[(1+\tau)\eta]^{-1}, \iota, 1-\iota, 0\}, \quad \iota \in (\alpha + \lambda_1^{-1}\lambda_2\alpha\gamma^{b-a}, 1],\\
&\hat{x}_2(s) = \{\alpha(1+\tau)\eta\pi^t\gamma^{b-t}, (1-\alpha)\gamma^b, 0, 0, 1\},\\
&\hat{x}_3(s) = \{\lambda_1\iota\pi^t, 0, \lambda_1\iota, 0, 0\},\\
&\hat{x}_4(s) = \{0, \lambda_1(1-\iota)\gamma^a + \lambda_2\gamma^b, \lambda_1(1-\iota), 0, \lambda_2\},\\
&\hat{x}_5(s) = \{-\lambda_1(\iota-\alpha)\pi^t + \lambda_2\alpha(1+\tau)\eta\pi^t\gamma^{b-t}, \lambda_1(\iota-\alpha)\gamma^t[(1+\tau)\eta]^{-1} - \lambda_2\alpha\gamma^b, 0, 0, 0\}.
\end{aligned}$$

Using that $\gamma^a = \gamma^t[(1+\tau)\eta]^{-1}$, the additional requirement that z be imported leads to

$$\iota > \alpha + \lambda_1^{-1}\lambda_2\alpha\gamma^{b-a}.$$

Given Assumption 3, the last inequality of (8d) implies that the right-hand side is smaller than 1, so $\iota \in (\alpha + \lambda_1^{-1}\lambda_2\alpha\gamma^{b-a}, 1]$.

Finally, case (v) comprises the remaining cases. z is then exported because there is too little production of y to export it. The conditions in (8e) follow by logically negating (8c) and (8d). ∎

Proof of Proposition 2. The proof of Proposition 2 is essentially the same as that of Proposition 1. We therefore highlight only the two differences. First, as in Lemma 2, we must replace η by $\eta(1+\tau)$. Note that doing this in Assumption 3 and rearranging, we can obtain the tariffs for which z is imported. This leads to the first inequality of conditions (9a) and (9b). Second, the presence of the tariff leads to an additional case that is absent with free trade, namely case (ii) of Lemma 2. For this case, it can be shown in much the same fashion as in case (i) that there is a unique value function and that it is optimal to adopt the best technology. ∎

Proof of Lemma 3. We start with the proof of case (i). Solving the problems of the two representative firms one finds $w_{yt} = \pi^t$, $w_{1t} = \gamma^a p_{zt}$, $w_{2t} = \gamma^b p_{zt}$. Since requiring type 1 to work in both sectors and type 2 to work in sector 2 is equivalent to $w_{yt} = w_{1t} < w_{2t}$, we have

$$p_{zt} = \pi^t \gamma^{-a}, \quad w_{yt} = w_{1t} = \pi^t, \quad w_{2t} = \pi^t \gamma^{b-a}.$$

Solving the problems of the two representative agents, we find that the period expenditure shares of the two goods are α and $1-\alpha$. Using that $p_{zt} = \pi^t \gamma^{-a}$, the equilibrium quantities consumed by the two types therefore are:

$$y_{1t} = \alpha \pi^t, \quad z_{1t} = (1-\alpha)\gamma^a, \quad y_{2t} = \alpha \pi^t \gamma^{b-a}, \quad z_{2t} = (1-\alpha)\gamma^b.$$

The period quantities of the two goods that are produced and their period exports and imports can be determined as follows. Using that the sum of the period quantities of z consumed by both types must equal the period production of z plus the period imports of z we get:

$$\lambda_1 z_{1t} + \lambda_2 z_{2t} = (l_{1t}\gamma^a + \lambda_2 \gamma^b)(1+Q).$$

Substituting z_{it} from above into this expression and solving for l_{1t} gives:

$$l_{1t} = \frac{(1-\alpha) - \lambda_1^{-1}\lambda_2(\alpha+Q)\gamma^{b-a}}{1+Q}.$$

Using the restriction $l_{yt} = 1 - l_{1t}$ it is now straightforward to compute the remaining variables:

$$\begin{aligned}
\hat{p}\ (s) =& \{1, \pi^t\gamma^{-a}, \pi^t, \pi^t, \pi^t\gamma^{b-a}\},\\
\hat{x}_1(s) =& \{\alpha\pi^t, (1-\alpha)\gamma^a, (1+\lambda_1^{-1}\lambda_2\gamma^{b-a})(\alpha+Q)(1+Q)^{-1},\\
& [(1-\alpha) - \lambda_1^{-1}\lambda_2(\alpha+Q)\gamma^{b-a}](1+Q)^{-1}, 0\},\\
\hat{x}_2(s) =& \{\alpha\pi^t\gamma^{b-a}, (1-\alpha)\gamma^b, 0, 0, 1\},\\
\hat{x}_3(s) =& \{(\lambda_1+\lambda_2\gamma^{b-a})\pi^t(\alpha+Q)(1+Q)^{-1}, 0, (\lambda_1+\lambda_2\gamma^{b-a})(\alpha+Q)(1+Q)^{-1}, 0, 0\},\\
\hat{x}_4(s) =& \{0, (\lambda_1\gamma^a+\lambda_2\gamma^b)(1-\alpha)(1+Q)^{-1}, 0, [\lambda_1(1-\alpha)-\lambda_2(\alpha+Q)\gamma^{b-a}](1+Q)^{-1}, \lambda_2\},\\
\hat{x}_5(s) =& \{-(\lambda_1+\lambda_2\gamma^{b-a})(1-\alpha)\pi^t Q(1+Q)^{-1}, (\lambda_1\gamma^a+\lambda_2\gamma^b)(1-\alpha)Q(1+Q)^{-1}, 0, 0, 0\}.
\end{aligned} \tag{26}$$

The final order of business is to check that the three required restrictions are met, that is, that $p_{zt} > p^*_{zt}$, that the quota is binding, and that $l_{z1t} \in (0,1)$. The first requirement is implied by $a < t - \log\eta/\log\gamma$. The second requirement can be checked as follows. For the parameters of case (i) we have that under the quota $z^*_t = (\lambda_1\gamma^a + \lambda_2\gamma^b)(1-\alpha)Q(1+Q)^{-1}$. If now $b < t - \log\eta/\log\gamma$, then from Lemma 1 we can see that under free trade $z_t^* = (\lambda_1 + \lambda_2)(1-\alpha)\gamma^t\eta^{-1}$.[20] Thus the quota binds:

$$\frac{(\lambda_1\gamma^a + \lambda_2\gamma^b)(1-\alpha)Q}{(1+Q)} < (\lambda_1+\lambda_2)(1-\alpha)\gamma^b \leq \frac{(\lambda_1+\lambda_2)(1-\alpha)\gamma^t}{\eta},$$

where the last inequality follows because $b < t - \log\eta/\log\gamma$ is equivalent to $\eta < \gamma^{t-b}$. If $b = t - \log\eta/\log\gamma > a$, then the largest possible imports under free trade are again $z_t^* = (\lambda_1+\lambda_2)(1-\alpha)\gamma^t\eta^{-1}$, so the same argument applies. If $b > t - \log\eta/\log\gamma \geq a$, then from Lemma 1 we can see that under free trade $z_t^* = \lambda_1(1-\alpha)\gamma^t\eta^{-1} - \lambda_2\alpha\gamma^b$. The first part of condition (11a) then is a necessary and sufficient condition for the quota to bind. The first part of the third requirement, $l_{z1t} > 0$, it trivially satisfied. The second part, $l_{z1t} < 1$, is equivalent to (11a).

We now turn to case (ii). We will only highlight the differences to the proof of case (i) and leave the rest as an exercise to the reader. We know that $l_{1t} = 0$ and $l_{2t} = 1$ because type i only works in sector i. Thus it must be that $w_{1t} \leq w_{yt} \leq w_{2t}$, implying that we cannot derive p_{zt} immediately from the equality of two wages.[21] p_{zt} can be obtained by using that total period consumption of z must equal period production plus imports of z. This gives:

$$p_{zt} = \frac{\lambda_1(1-\alpha)\pi^t}{\lambda_2(\alpha+Q)\gamma^b}$$

Given p_{zt}, it is straightforward to derive the other variables:

$$\begin{aligned}
\hat{p}\ (s) =& \{1, \lambda_1\lambda_2^{-1}(1-\alpha)\pi^t(\alpha+Q)^{-1}\gamma^{-b}, \pi^t, \lambda_1\lambda_2^{-1}(1-\alpha)\pi^t(\alpha+Q)^{-1}\gamma^{a-b}, \\
& \lambda_1\lambda_2^{-1}(1-\alpha)\pi^t(\alpha+Q)^{-1}\}, \\
\hat{x}_1(s) =& \{\alpha\pi^t, \lambda_1^{-1}\lambda_2(\alpha+Q)\gamma^b, 1, 0, 0\}, \\
\hat{x}_2(s) =& \{\lambda_1\lambda_2^{-1}\alpha(1-\alpha)\pi^t(\alpha+Q)^{-1}, (1-\alpha)\gamma^b, 0, 0, 1\}, \\
\hat{x}_3(s) =& \{\lambda_1\pi^t, 0, \lambda_1, 0, 0\}, \\
\hat{x}_4(s) =& \{0, \lambda_2\gamma^b, 0, 0, \lambda_2\}, \\
\hat{x}_5(s) =& \{-\lambda_1(1-\alpha)\pi^t Q(\alpha+Q)^{-1}, \lambda_2 Q\gamma^b, 0, 0, 0\}.
\end{aligned} \tag{27}$$

We complete case (ii) by showing that $p_{zt} > p_{zt}^*$, that the quota is binding, and

[20] Note that in case the equilibrium is indeterminate, we make the comparison for the equilibrium that is selected as the limit of a sequence of nearby determinate equilibria.

[21] Note that $w_{1t} = w_{yt}$ ($w_{2t} = w_{yt}$) can be consistent with type 1 (type 2) being indifferent between working in either sector but in fact working in sector 1 (sector 2) only.

that $w_{1t} \leq w_{yt} \leq w_{2t}$. The first requirement is equivalent to:

$$Q < \frac{\lambda_1(1-\alpha)\gamma^{t-b}}{\lambda_2\eta} - \alpha,$$

which is the first inequality of (11b). The second requirement can be checked as follows. If $b \leq t - \log\eta/\log\gamma$, then the imports under the quota are $\lambda_2 Q\gamma^b$ and the imports under free trade are at most $(\lambda_1+\lambda_2)(1-\alpha)\gamma^t\eta^{-1}$; see Lemma 1 for the latter. The first inequality of condition (11b) then implies that the quota binds:

$$Q \leq \frac{\lambda_1(1-\alpha)}{\lambda_2} - \alpha < \frac{\lambda_1(1-\alpha)\gamma^{t-b}}{\lambda_2} + (1-\alpha)\gamma^{t-b}.$$

If $b > t - \log\eta/\log\gamma$, then the imports under free trade become $\lambda_1(1-\alpha)\gamma^t\eta^{-1} - \lambda_2\alpha\gamma^t$. Therefore, the first inequality of condition (11b) is a necessary and sufficient condition for the quota to bind. The third requirement is equivalent to

$$\frac{\lambda_1(1-\alpha)}{\lambda_2\gamma^{b-a}} - \alpha \leq Q \leq \frac{\lambda_1(1-\alpha)}{\lambda_2} - \alpha,$$

which is implied by (11b). Note that if there are equality signs in these two inequalities, then still type 1 works in the y sector and type 2 in sector 2. This can be seen as follows. If $Q = \frac{\lambda_1(1-\alpha)}{\lambda_2\gamma^{b-a}} - \alpha$, then $l_{z1} = 0$ in case (i), that is, the first type no longer works in sector 2. If $Q = \frac{\lambda_1(1-\alpha)}{\lambda_2} - \alpha$, then $l_{y1} = 0$ in case (iii) below, that is, the second type no longer works in the y sector.

We continue with case (iii). Given that type 2 works in both sectors $w_{1t} \leq w_{yt} = w_{2t}$, implying that $p_{zt} = \pi^t\gamma^{-b}$. The rest of the equilibrium can be computed in much the same way as the equilibrium in case (i). The result is:

$$\begin{aligned}
\hat{p}\ (s) =& \{1, \pi^t\gamma^{-b}, \pi^t, \pi^t\gamma^{-a}, \pi^t\}, \qquad (28)\\
\hat{x}_1(s) =& \{\alpha\pi^t, (1-\alpha)\gamma^b, 1, 0, 0\},\\
\hat{x}_2(s) =& \{\alpha\pi^t, (1-\alpha)\gamma^b, [(\alpha+Q)-\lambda_1\lambda_2^{-1}(1-\alpha)](1+Q)^{-1}, 0, (\lambda_1\lambda_2^{-1}+1)(1-\alpha)(1+Q)^{-1}\},\\
\hat{x}_3(s) =& \{(\lambda_1+\lambda_2)\pi^t(\alpha+Q)(1+Q)^{-1}, 0, (\lambda_1+\lambda_2)(\alpha+Q)(1+Q)^{-1}, 0, 0\},\\
\hat{x}_4(s) =& \{0, (\lambda_1+\lambda_2)\gamma^b(1-\alpha)(1+Q)^{-1}, 0, 0, (\lambda_1+\lambda_2)(1-\alpha)(1+Q)^{-1}\},\\
\hat{x}_5(s) =& \{-(\lambda_1+\lambda_2)\pi^t(1-\alpha)Q(1+Q)^{-1}, (\lambda_1+\lambda_2)\gamma^b(1-\alpha)Q(1+Q)^{-1}, 0, 0, 0\}.
\end{aligned}$$

Checking the three requirements in this case is straightforward. First, $p_{zt} > p^*_{zt}$ is satisfied if the second part of condition (11c) holds. Second, the quota can be shown to bind without further restrictions. Third, $l_{zt} > 0$ without further restrictions and $l_{zt} \leq 1$

is satisfied if the first part of condition (11c) holds.

At the end, we address case (iv). This amounts to showing that if the parameters are as in case (iv) there cannot be other equilibria with the desired properties. There only two logical possibilities left for equilibria that we have not so far considered. The first possibility is that $w_y < w_1 < w_2$ in equilibrium. However, this cannot be because then all agents would work in the second sector and z would be exported. The second possibility that we have not so far considered is that $w_1 < w_2 < w_y$ in equilibrium. In this case, all agents would work in the first sector when there is the quota. Then for the same technology parameters there are two possibilities under free trade. First, under free trade at least some type-2 agents work in sector 2. However, if this was the case then the relative price of z under the quota would fall short of that under free trade. This is not allowed. Second, under free trade all type-2 agents work in sector 1. However, this means that the imports of z under free trade and under the quota would be the same (because in both cases all agents work in sector 1), so the quota would not bind. This completes the proof. ■

Proof of Proposition 3. We start with case (i) of the proposition, that is, Condition (12a) holds. It has two subcases. In the first subcase the coalition blocks for $\tilde{b}-\tilde{a}$ periods where $\tilde{a}$ and $\tilde{b}$ satisfy the second part of condition (11a) .[22] The period equilibrium is then as in case (i) of Lemma 3 and the present value of the indirect utility of type 2 is given by:

$$\sum_{t=0}^{\infty} \tilde{\beta}^t u(\tilde{a}, \tilde{b}, \tilde{t}) = \Psi \sum_{t=0}^{\infty} \tilde{\beta}^t \gamma^{(\tilde{b}-\tilde{a})\alpha\rho+\tilde{b}(1-\alpha)\rho}, \tag{29}$$

where

$$\Psi \equiv \frac{\alpha^{\alpha\rho}(1-\alpha)^{(1-\alpha)\rho}}{\rho}.$$

In the second subcase the coalition blocks for $\tilde{b}-\tilde{a}$ periods where $\tilde{a}$ and $\tilde{b}$ satisfy the second part of condition (11b).[23] The period equilibrium is then as in case (ii) of Lemma 3 and the present value of the indirect utility of type 2 is given by:

$$\sum_{t=0}^{\infty} \tilde{\beta}^t u(\tilde{a}, \tilde{b}, \tilde{t}) = \Psi \sum_{t=0}^{\infty} \tilde{\beta}^t \left[\frac{\lambda_1(1-\alpha)}{\lambda_2(\alpha+Q)}\right]^{\alpha\rho} \gamma^{\tilde{b}(1-\alpha)\rho}. \tag{30}$$

We again use Theorem 4.6 of Stokey and Lucas (1989) to establish that a unique

[22] We are using the same notation and stationary transformations as in Propositions 1 and 2.

[23] Note that $\tilde{b}-\tilde{a} = b - a$.

value function exists. We set

$$\mathcal{X} \equiv \left[-\frac{\log\{\lambda_1(1-\alpha)/[\lambda_2(\alpha+Q)]\}}{\log\gamma} - 1, 1 \right].$$

From (30), we can see that if it is optimal to be in the second subcase then it cannot be optimal to block for more periods than is necessary to remain in that subcase, thus $\tilde{b} \in \mathcal{X}$. Obviously, $\mathcal{X}$ is bounded and compact. Moreover, $\Gamma : \mathcal{X} \to \mathcal{X}$ defined by $\Gamma(\tilde{b}) = [\tilde{b}, 1]$ is nonempty, compact-valued, continuous and monotone. Then, let $A \equiv \{(\tilde{b}, \tilde{b}') \in \mathcal{X}^2 : \tilde{b}' \in \Gamma(\tilde{b})\}$ and $F : A \to R_+$ with

$$F(\tilde{b}, \tilde{b}') = \begin{cases} \Psi\gamma^{(\tilde{b}-\tilde{a})\alpha\rho+\tilde{b}(1-\alpha)\rho}, & \text{if } \tilde{b}-\tilde{a} < \frac{\log\{\lambda_1(1-\alpha)/[\lambda_2(\alpha+Q)]\}}{\log\gamma} \\ \Psi\left[\frac{\lambda_1(1-\alpha)}{\lambda_2(\alpha+Q)}\right]^{\alpha\rho}\gamma^{\tilde{b}(1-\alpha)\rho}, & \text{if } \tilde{b}-\tilde{a} \geq \frac{\log\{\lambda_1(1-\alpha)/[\lambda_2(\alpha+Q)]\}}{\log\gamma} \end{cases}. \tag{31}$$

F thus defined is continuous and bounded. Therefore, Theorem 4.6 of Stokey and Lucas (1989) implies that there exists a unique value function v that solves the coalition's problem.

The last step to establish case (i) of the proposition is to show that if α is sufficiently large, then adopting the most efficient technology is not an equilibrium. We first show that if α is sufficiently large, then it is optimal to choose $\tilde{a}$ and $\tilde{b}$ such that the first case of (31) applies. From (29) and (30), the condition for this to be the case is:[24]

$$\Psi\sum_{t=0}^{\infty}\tilde{\beta}^t\left\{\gamma^{[\tilde{b}(1)-\tilde{a}(1)]\alpha\rho+\tilde{b}(1)(1-\alpha)\rho} - \left[\frac{\lambda_1(1-\alpha)}{\lambda_2(\alpha+Q)}\right]^{\alpha\rho}\gamma^{\tilde{b}(2)(1-\alpha)\rho}\right\} > 0. \tag{32}$$

A sufficient condition for this to hold is that in every period

$$\gamma^{[\tilde{b}(1)-\tilde{a}(1)]\alpha\rho+[\tilde{b}(1)-\tilde{b}(2)](1-\alpha)\rho} \geq \left[\frac{\lambda_1(1-\alpha)}{\lambda_2(\alpha+Q)}\right]^{\alpha\rho} \tag{33}$$

and in at least one period the inequality is strict. We know that $b(1) - b(2)$ is bounded because in the second case of (31) it is not optimal to block for more periods than is necessary to stay in that case. We also know that given our initial conditions $\tilde{b}(1)-\tilde{a}(1) \geq 1$. So as α goes to 1 the left-hand side of (33) goes to a limit that is not smaller than 1 and the right-hand side goes to zero. Thus, there is an $\bar{\alpha} \in (0, 1)$ such that for all $\alpha \in [\bar{\alpha}, 1)$ (32) holds. Note that for each $\alpha \in [\bar{\alpha}, 1)$ condition (12a) will still hold if λ_1 is sufficiently large and λ_2 is sufficiently small. We can now turn to showing that for α sufficiently large, it optimal not to adopt the most efficient technology. For α sufficiently

[24] We indicate the two cases by using the arguments (1) and (2).

large, the present value of utility when the most efficient technology is adopted is:

$$\sum_{t=0}^{\infty} \tilde{\beta}^t u(-1,0,0) = \Psi \sum_{t=0}^{\infty} \tilde{\beta}^t \gamma^{\alpha\rho}. \tag{34}$$

If the most efficient technology is blocked one period then the present value of utility is:

$$\sum_{t=0}^{\infty} \tilde{\beta}^t u(\tilde{a},\tilde{b},\tilde{t}) = \Psi \sum_{t=0}^{\infty} \tilde{\beta}^t \gamma^{2\alpha\rho+(1-\alpha)\rho\tilde{b}}. \tag{35}$$

Comparing these two expressions shows that $\alpha > 2/3$ is a sufficient condition for the latter to dominate the former, In sum we have shown that when α is large enough, then there is a feasible strategy that dominates adopting the most efficient technology.

We continue by showing that if α is sufficiently small, then the most efficient technology is always adopted. To see this, note that (33) also holds as α goes to zero, where the inequalities will be strict when there is blocking in the second case of (31). That implies that the first case of (31) is the relevant one also for α close to zero. (29) then shows that for α close to zero, it is optimal to adopt the best technology.

We complete the proof by addressing case (ii) of the proposition, that is, (12b) holds. This puts us into cases (iii) or (iv) of Lemma 3. In case (iv) there is no period equilibrium under the quota, implying that we can restrict attention to case (iii). So suppose that condition (11c) holds. The period equilibrium in case (iii) is such that y_{2t} and z_{2t} are independent of a and z_{2t} increases in b. Therefore the coalition again would want to choose $b = t$. Since $\eta, \gamma > 1$ this violates the second part of (11c). ■

Proof of Proposition 4. We start by proving the statement about the growth rates. Under all three trade policy regimes, all variables related to sector 1 grow at the rate π, that is,

$$\frac{y_{t+1}}{y_t} = \frac{y_{it+1}}{y_{it}} = \frac{y^*_{t+1}}{y^*_t} = \pi \quad \forall\, t \in \{0,1,2,...\}.$$

Moreover, under free trade and a tariff, all variables related to sector 2 grow at the rate γ, that is,

$$\frac{z_{t+1}}{z_t} = \frac{z_{it+1}}{z_{it}} = \frac{z^*_{t+1}}{z^*_t} = \gamma \quad \forall\, t \in \{0,1,2,...\}.$$

If the most efficient technology is adopted, this is the case too under the quota. If not, then the *average* growth rate of sector 2 still equals γ. This follows from the fact that when there is blocking, b will after finitely many periods be adjusted to the frontier. Thus, the average growth rate of b is the growth rate of the frontier, that is, γ. Since except for the initial value, a equals the previous b, the average growth rate of a converges to γ as time goes to infinity.

Given the measure of TFP from the text, the claims about TFP (in international prices) can be seen as follows. The marginal product of time in sector 1 equals π^t irrespective of the trade policy regime. Under free trade or the tariff, the marginal product of time in sector 2 is $\eta\pi^t$. The reason is that the most efficient technology is used at all time and generically only type-2 agents work in sector 2.[25] In contrast, under a quota there are two cases. If there is blocking, then the average marginal product of all agents working in sector 2 is smaller than possible. Thus, average TFP is smaller than under the other two trade policy regimes. If there is no blocking and the most efficient technology is adopted, then type 1 agents also work in sector 2. Although each type produces with the most efficient technology average TFP of sector 2 goes down because some type 1 agents produce there now at lower productivity than in sector 1, which in international prices equals $\eta\gamma^{-1}\pi^t < \pi^t$. Evaluating average TFP of the economy at international prices, it is straightforward to see that this goes down too. The proof is completed by noting that per capita national income in international prices moves like TFP in international prices. ■

Proof of Proposition 5. Using the results of Lemmata 1–3 and Propositions 1–3, we find that the present values of the type 1's indirect utilities under the three trade policy regimes are given by:[26]

$$\text{Utility under free trade} = \Psi \sum_{t=0}^{\infty} \tilde{\beta}^t \frac{1}{\eta^{(1-\alpha)\rho}}, \tag{36a}$$

$$\text{Utility under tariff} = \Psi \sum_{t=0}^{\infty} \tilde{\beta}^t \frac{1}{[(1+\tau)\eta]^{(1-\alpha)\rho}}, \tag{36b}$$

$$\text{Utility under quota if (11a)} = \Psi \sum_{t=0}^{\infty} \tilde{\beta}^t \gamma^{\tilde{a}(1-\alpha)\rho}, \tag{36c}$$

$$\text{Utility under quota if (11b)} = \Psi \left[\frac{\lambda_2(\alpha+Q)}{\lambda_1(1-\alpha)}\right]^{(1-\alpha)\rho} \sum_{t=0}^{\infty} \tilde{\beta}^t \gamma^{\tilde{b}(1-\alpha)\rho}. \tag{36d}$$

These expression immediately imply all claims of part (i), except that free trade dominates the quota when (11b) holds. This follows because, as we saw in the proof of the previous proposition, it is never optimal to choose a $\tilde{b} - \tilde{a}$ that exceeds the right-hand

[25] By generically we mean that this is the case except in the measure–zero case in which type–1 agents work in both sectors.

[26] The notation is as in the previous propositions: $\tilde{\beta} = \beta\pi^{\alpha\rho}\gamma^{(1-\alpha)\rho}$, $\Psi = \alpha^{\alpha\rho}(1-\alpha)^{(1-\alpha)\rho}/\rho$, $\tilde{a} = a-t$, and $\tilde{b} = b-t$.

side of condition (11b) by more than one, so

$$\gamma^b \frac{\lambda_2(\alpha + Q)}{\lambda_1(1-\alpha)} < \gamma^{a+1}.$$

Since $a + 1 \leq t - 1$ when (11b) holds, the claim follows.

The normalized present values of the type 2's indirect utilities under the three trade policy regimes are given by:

$$\text{Utility under free trade} = \Psi \sum_{t=0}^{\infty} \tilde{\beta}^t \eta^{\alpha\rho}, \tag{37a}$$

$$\text{Utility under tariff} = \Psi \sum_{t=0}^{\infty} \tilde{\beta}^t [(1+\tau)\eta]^{\alpha\rho}, \tag{37b}$$

$$\text{Utility under quota if (11a)} = \Psi \sum_{t=0}^{\infty} \tilde{\beta}^t \gamma^{(\tilde{b}-\tilde{a})\alpha\rho + \tilde{b}(1-\alpha)\rho}, \tag{37c}$$

$$\text{Utility under quota if (11b)} = \Psi \left[\frac{\lambda_1(1-\alpha)}{\lambda_2(\alpha+Q)}\right]^{\alpha\rho} \sum_{t=0}^{\infty} \tilde{\beta}^t \gamma^{\tilde{b}(1-\alpha)\rho}. \tag{37d}$$

These expression immediately imply all claims of part (ii), except that the quota dominates free trade. This follows by setting $b = t$ under the quota, which is feasible and gives type 2 a higher utility than under free trade. ■

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