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A Ricardian rationale for the WTO rules on R&D subsidies

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A B S T R A C T

The WTO subsidy rules use two key criteria, specificity and adverse effects, to regulate R&D subsidies. Using the model of Dornbusch et al. (1977), we offer a Ricardian rationale for the regulatory criteria.

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1. Introduction

According to the Agreement on Subsidies and Countervailing Measures (SCM Agreement), the WTO uses two key criteria, specificity and adverse effects, to regulate R&D subsidies. Namely, if R&D subsidies are specifically targeted and cause adverse effects to another member, they are actionable.[1] Using the standard Ricardian model of Dornbusch et al. (1977), we associate specificity with subsidies targeting a specific interval of goods, and adverse effects with subsidies extending the export boundary.[2] We find that specifically targeted R&D subsidies can always be used as beggar-thy-neighbor policies when they are unregulated, and they are likely to be so only when they extend the export boundary.

Despite extensive debates on the SCM Agreement, our paper is the first to offer a rationale for its regulatory criteria.[3] Koh and Lee (2020) show empirical evidence that unregulated R&D subsidies are used to change trade patterns without bringing innovations. Itoh and Kiyono (1987) predict that specifically targeted R&D subsidies may cause beggar-thy-neighbor effects when the government R&D budget is exogenous and freely provided. In association with the two criteria of the SCM Agreement, we formally verify that unregulated R&D subsidies can always be devised as beggar-thy-neighbor policies when the government R&D budget is endogenous, even under the risk of the budget being mostly wasted.

2. A Ricardian model with specific R&D subsidies

We consider the Dornbusch et al. (1977) model in which two countries, Home and Foreign, have competitive markets and trade under zero-tariff commitments. With a continuum of goods on [0, 1], the model provides a simple way to associate specificity with subsidies targeting a specific interval of goods.

Home and Foreign have factor endowments, L and L^*, with wages, w and w^*, respectively. Their technologies are captured by the unit labor requirements for good z, $a(z)$ and $a^*(z)$. The relative productivity, $\frac{a^*(z)}{a(z)}$, is continuous and strictly decreasing in z. The unit production cost of good z equals $wa(z)$ in Home. Home offers the R&D subsidy $s(z)wa(z)$ for $z \in [z_1, z_2]$. Its policy variables are the subsidy rate and subsidy interval, $s(z) > 0$ and $[z_1, z_2]$. The subsidy for z decreases its production cost by $\gamma(z)s(z)wa(z)$, where $\gamma(z) > 0$ captures the effectiveness of the subsidy.[4] Given $s(z) > 0$, if $\gamma(z)$ is larger, the subsidy is more effective at increasing productivity, and if $\gamma(z)$ is close to zero, the

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1 Actionable subsidies are subject to challenge in the WTO or to countervailing measures.

2 The SCM Agreement lists three adverse effects: (i) injury to a domestic industry caused by subsidized imports, (ii) a loss of exports in the subsidizing- or a third-country market, and (iii) the nullification or impairment of the market access expected from a bound tariff reduction.

3 Lee (2016) offers a comprehensive survey of literature on the SCM Agreement.

4 The term $\gamma(z)s(z)$ can be generalized by $\gamma(z)\sigma(s(z))$, where $\sigma'(\cdot) > 0$.

subsidy is mostly wasted with little effect. We focus on $\gamma(z)s(z) < 1$.

The trade equilibrium is built on requirements on production and demand sides. We denote the combinations of the export boundary and relative wage by $(\widehat{z}, \omega)$, where $\omega \equiv \frac{w}{w^*}$. We then define the production-side requirement as $(\widehat{z}, \omega)$ that satisfy

$$\alpha(z) \geq \omega \text{ for } z \in [0, \widehat{z}] \text{ and } \alpha(z) < \omega \text{ for } z \in (\widehat{z}, 1], \tag{1}$$

where $\alpha(z)$ is the relative productivity for Home:

$$\alpha(z) \equiv \begin{cases} \dfrac{1}{1-\gamma(z)s(z)} \dfrac{a^*(z)}{a(z)} & \text{for } z \in [z_1, z_2] \\ \dfrac{a^*(z)}{a(z)} & \text{for } z \notin [z_1, z_2]. \end{cases}$$

Thus, Home (Foreign) has a comparative advantage for $z \leq \widehat{z}$ $(z > \widehat{z})$.

On the demand side, Home and Foreign consumers have Cobb–Douglas preferences,

$$\int_0^1 b(z) \ln c(z) dz \text{ and } \int_0^1 b^*(z) \ln c^*(z) dz,$$

where $\int_0^1 b(z)dz = \int_0^1 b^*(z)dz = 1$. Given zero profits, indirect utility functions represent welfare if the government budget is balanced. To find Home welfare, we use the consumer problem,

$$\max_{c(z)} \int_0^1 b(z) \ln c(z) dz \text{ subject to } \int_0^1 p(z)c(z)dz \leq Y,$$

and substitute the consumer's choice, $c(z) = b(z)\frac{Y}{p(z)}$, with marginal-cost pricing,

$$p(z) = \begin{cases} w[1-\gamma(z)s(z)]a(z) & \text{for } z \leq \widehat{z} \text{ and } z \in [z_1, z_2] \\ wa(z) & \text{for } z \leq \widehat{z} \text{ and } z \notin [z_1, z_2] \\ w^*a^*(z) & \text{for } z > \widehat{z}. \end{cases}$$

There are two requirements on the demand side. First, the government R&D budget is financed by labor income,

$$\int_{z_1}^{z_2} s(z)wa(z)dz = \rho wL, \tag{2}$$

where ρ represents the share of the R&D budget in gross labor income. Second, the value of Home imports equals the value of Home exports,

$$\int_{\widehat{z}}^1 b(z)dz \cdot (1-\rho)wL = \int_0^{\widehat{z}} b^*(z)dz \cdot w^*L^*, \tag{3}$$

where $(1-\rho)wL = Y$ and $w^*L^* = Y^*$. Combining (2) and (3), we define the demand-side requirement as $(\widehat{z}, \omega)$ that satisfy

$$\omega = \beta(\widehat{z}), \tag{4}$$

where

$$\beta(\widehat{z}) \equiv \frac{L^*}{(1-\rho)L} \frac{\int_0^{\widehat{z}} b^*(z)dz}{\int_{\widehat{z}}^1 b(z)dz} = \frac{L^*}{L - \int_{z_1}^{z_2} s(z)a(z)dz} \frac{\int_0^{\widehat{z}} b^*(z)dz}{\int_{\widehat{z}}^1 b(z)dz}.$$

Finally, we define the trade equilibrium as $(\widehat{z}, \widehat{\omega})$ that satisfies the requirements (1) and (4). Once the export boundary $\widehat{z}$ is determined, the relative income, $y \equiv \frac{Y}{Y^*}$, is determined by (3),

$$\widehat{y} = \frac{\int_0^{\widehat{z}} b^*(z)dz}{\int_{\widehat{z}}^1 b(z)dz}. \tag{5}$$

We define

$$P \equiv \{z : z_1 \leq z \leq z_2\} \cap \{z : \alpha(z) \geq \widehat{\omega}\},$$

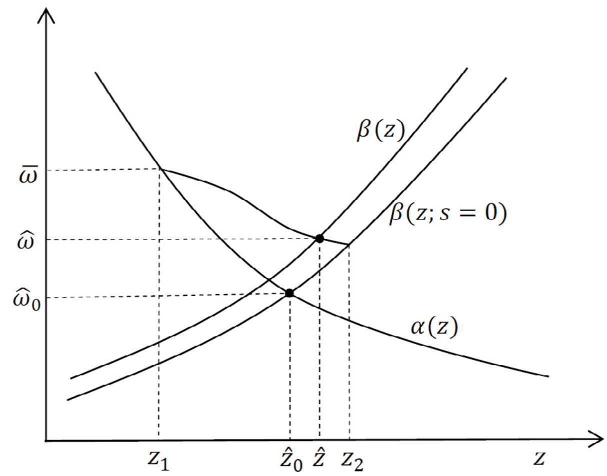

Fig. 1. An illustration of R&D subsidies on $[z_1, z_2]$.

to reflect that prices convey the productivity effects, $p(z) = w[1-\gamma(z)s(z)]a(z)$, only for $z \in P$.[5] We rewrite indirect utility functions to derive the equilibrium welfare from endogenous variables, $\widehat{z}$, $\widehat{\omega}$, and $\widehat{y}$:

$$v = B + \ln \widehat{y} + \ln L^* - (\ln \widehat{\omega}) \int_0^{\widehat{z}} b(z)dz - \int_0^{\widehat{z}} b(z) \ln a(z)dz \tag{6}$$
$$- \int_{\widehat{z}}^1 b(z) \ln a^*(z)dz - \int_{z \in P} b(z) \ln[1-\gamma(z)s(z)]dz \text{ and}$$

$$v^* = B^* + \ln L^* - (\ln \widehat{\omega}) \int_0^{\widehat{z}} b^*(z)dz - \int_0^{\widehat{z}} b^*(z) \ln a(z)dz \tag{7}$$
$$- \int_{\widehat{z}}^1 b^*(z) \ln a^*(z)dz - \int_{z \in P} b^*(z) \ln[1-\gamma(z)s(z)]dz,$$

where $B \equiv \int_0^1 b(z) \ln b(z)dz$ and $B^* \equiv \int_0^1 b^*(z) \ln b^*(z)dz$.

Without subsidies, the original equilibrium $(\widehat{z}_0, \widehat{\omega}_0)$ satisfies $\widehat{\omega}_0 = \alpha(\widehat{z}_0; s=0) = \beta(\widehat{z}_0; s=0)$,

$$\widehat{\omega}_0 = \frac{a^*(\widehat{z}_0)}{a(\widehat{z}_0)} = \frac{L^*}{L} \frac{\int_0^{\widehat{z}_0} b^*(z)dz}{\int_{\widehat{z}_0}^1 b(z)dz}. \tag{8}$$

We can obtain $\widehat{y}_0$ from (5) and the original welfare, v_0 and v_0^*, from (6) and (7). With subsidies, the function $\beta(z; s=0)$ shifts to $\beta(z)$ on the entire range as if endowment L decreases to $(1-\rho)L$. We thus obtain the following lemma.

Lemma 1. *The relative wage increases with R&D subsidies,* $\widehat{\omega} = \beta(\widehat{z}) > \widehat{\omega}_0$.

3. A rationale for the two criteria

Suppose that Home offers R&D subsidies for $z \in [z_1, z_2]$ such that $\alpha(z)$ is nonincreasing on $[z_1, z_2]$ with the boundary conditions: $s(z_1) = 0$ and $\alpha(z_2) = \beta(z_2; s=0)$. For a given shift of $\alpha(z)$ on $[z_1, z_2]$, if $\gamma(z)$ is smaller, $\beta(z)$ shifts more since a higher $s(z)$ is needed and the consequent larger R&D budget should be financed with a larger ρ (see Fig. 1).

Formally, we rewrite the supply-side equation,

$$\alpha(z) = \frac{1}{1-\gamma(z)s(z)} \frac{a^*(z)}{a(z)} \text{ for } z \in [z_1, z_2],$$

[5] Home cannot keep its comparative advantage on $[z_1, z_2]$ if subsidies raise the relative wage more than the relative productivity, $\alpha(z) < \widehat{\omega}$, for some $z \in [z_1, z_2]$.

and put it into the demand-side function such that the equilibrium $(\widehat{z}, \widehat{\omega})$ is defined by

$$\widehat{\omega} = \frac{L^*}{L - \int_{z_1}^{z_2} \left(\frac{\alpha(z) - a^*(z)/a(z)}{\alpha(z)\gamma(z)}\right) a(z)dz} \frac{\int_0^{\widehat{z}} b^*(z)dz}{\int_{\widehat{z}}^1 b(z)dz},$$

where $\alpha(z)$ is nonincreasing and $\alpha(\widehat{z}) = \widehat{\omega}$.

We establish two findings. First, for any $\gamma(z) > 0$, if z_1 is sufficiently close to $\widehat{z}_0$, Home can extend its comparative advantage, $\alpha(z) \geq \widehat{\omega}$, beyond $\widehat{z}_0$ by targeting a sufficiently narrow interval of goods. We now use the equilibrium $(\widehat{z}, \widehat{\omega})$ with $\widehat{z} > \widehat{z}_0$ and calculate the welfare effects:

$$v - v_0 = [\ln \widehat{\omega}_0 - \ln \widehat{\omega}] \int_0^{\widehat{z}_0} b(z)dz - \int_{z_1}^{\widehat{z}_0} b(z) \ln[1 - \gamma(z)s(z)]dz \tag{9}$$

$$+ \int_{\widehat{z}_0}^{\widehat{z}} b(z) [\ln \alpha(z) - \ln \widehat{\omega}]\, dz + [\ln \widehat{y} - \ln \widehat{y}_0] \text{ and}$$

$$v^* - v_0^* = [\ln \widehat{\omega}_0 - \ln \widehat{\omega}] \int_0^{\widehat{z}_0} b^*(z)dz - \int_{z_1}^{\widehat{z}_0} b^*(z) \ln[1 - \gamma(z)s(z)]dz + \int_{\widehat{z}_0}^{\widehat{z}} b^*(z) [\ln \alpha(z) - \ln \widehat{\omega}]\, dz. \tag{10}$$

The first terms in (9) and (10) show the welfare losses from Home producing the original Home-produced goods at a higher relative wage. The second and third terms respectively represent the welfare gains from the productivity effects on the original Home-produced goods and from Home extending its comparative advantage on $[\widehat{z}_0, \widehat{z}]$. The last term in (9) represents Home welfare gains from its increased relative income, $\widehat{y} > \widehat{y}_0$.

Second, we verify beggar-thy-neighbor effects, $v > v_0$ and $v^* < v_0^*$. To this end, we first calculate the marginal effects of extending comparative advantage, $\frac{d(v-v_0)}{d\widehat{z}}$ and $\frac{d(v^*-v_0^*)}{d\widehat{z}}$, and then show that if z_1 approaches $\widehat{z}_0$, they approach terms with opposite signs:

$$\frac{d(v - v_0)}{d\widehat{z}} \to \left(\frac{b(\widehat{z}_0)}{\int_{\widehat{z}_0}^1 b(z)dz} + \frac{b^*(\widehat{z}_0)}{\int_0^{\widehat{z}_0} b^*(z)dz} \right) \int_{\widehat{z}_0}^1 b(z)dz \text{ and}$$

$$\frac{d(v^* - v_0^*)}{d\widehat{z}} \to -\left(\frac{b(\widehat{z}_0)}{\int_{\widehat{z}_0}^1 b(z)dz} + \frac{b^*(\widehat{z}_0)}{\int_0^{\widehat{z}_0} b^*(z)dz} \right) \int_0^{\widehat{z}_0} b^*(z)dz.$$

This finding shows that if Home targets a sufficiently narrow interval of goods near $\widehat{z}_0$, trade balance is achieved at $\widehat{z} > \widehat{z}_0$ with negative externalities: the original Foreign-produced goods $z \in [\widehat{z}_0, 1]$ become more affordable for Home consumers, whereas the original Home-produced goods $z \in [0, \widehat{z}_0]$ become less affordable for Foreign consumers.

Proposition 1. *Suppose that Home offers R&D subsidies for $z \in [z_1, z_2]$ such that $\alpha(z)$ is nonincreasing on $[z_1, z_2]$ with the boundary conditions: $s(z_1) = 0$ and $\alpha(z_2) = \beta(z_2; s = 0)$. If z_1 is sufficiently close to $\widehat{z}_0$, then $\widehat{z} > \widehat{z}_0$ and $v > v_0$ and $v^* < v_0^*$.*

Proposition 1 shows that if specifically targeted R&D subsidies are unregulated, they can always be used to extend the original comparative advantage and cause beggar-thy-neighbor effects. Although R&D subsidies are specifically targeted, Proposition 2 finds that if $\widehat{z} \leq \widehat{z}_0$, they are unlikely to be beggar-thy-neighbor policies.

Proposition 2. *Suppose that R&D subsidies do not extend the export boundary, $\widehat{z} \leq \widehat{z}_0$. (i) If $\gamma(z)$ is sufficiently large for $z \in P$ and P is sufficiently large, then $v > v_0$ and $v^* > v_0^*$. (ii) If $b(z) = b^*(z)$ for all $z \in [0, \widehat{z}_0]$, then $v - v_0 \leq v^* - v_0^*$.*

Intuitively, the result (ii) is immediate under a more restrictive assumption that $b(z) = b^*(z)$ for all $z \in [0, 1]$: given (6) and (7), the welfare differential between two countries depends on the relative income, $v - v^* = \ln \widehat{y}$ and $v_0 - v_0^* = \ln \widehat{y}_0$, and $\widehat{z} \leq \widehat{z}_0$ implies $\ln \widehat{y} \leq \ln \widehat{y}_0$. Overall, our findings provide a Ricardian legitimacy for the regulatory criteria, specificity and adverse effects. Our findings imply that the WTO subsidy rules may serve to curb the use of specifically targeted R&D subsides for the beggar-thy-neighbor purpose.

4. Conclusion

Using the Dornbusch et al. (1977) model, we offer a Ricardian rationale for the key regulatory criteria: specificity and adverse effects. This study is a good starting point to assess the multilateral regulations on R&D subsidies in generalized settings in future work.

Appendix

A.1. Proof of Proposition 1

The proof consists of two parts. In the first part, we prove that $\widehat{z} > \widehat{z}_0$ under the assumption that z_1 is sufficiently close to $\widehat{z}_0$. Given that $\widehat{\omega} > \widehat{\omega}_0$ in Lemma 1, it suffices to show that $\widehat{z}$ and $\widehat{\omega}$ are positively related, $\frac{d\widehat{\omega}}{d\widehat{z}} > 0$, under the assumption. We define the equilibrium $(\widehat{z}, \widehat{\omega})$ by the implicit function,

$$\Phi(\widehat{z}, \widehat{\omega}) \equiv \widehat{\omega} - \frac{L^*}{(1-\rho)L} \frac{\int_0^{\widehat{z}} b^*(z)dz}{\int_{\widehat{z}}^1 b(z)dz} = 0, \tag{11}$$

where

$$\rho = \frac{1}{L} \int_{z_1}^{z_2} s(z)a(z)dz = \frac{1}{L} \int_{z_1}^{z_2} \left(\frac{\alpha(z) - a^*(z)/a(z)}{\alpha(z)\gamma(z)} \right) a(z)dz.$$

We use (11) and derive

$$\frac{d\widehat{\omega}}{d\widehat{z}} = -\frac{\partial \Phi / \partial \widehat{z}}{\partial \Phi / \partial \widehat{\omega}}. \tag{12}$$

With $\widehat{z}$ held constant, the denominator of (12) becomes

$$\frac{\partial \Phi}{\partial \widehat{\omega}} = 1 - \frac{L^*[s(z_2)a(z_2)\frac{dz_2}{d\widehat{\omega}} - s(z_1)a(z_1)\frac{dz_1}{d\widehat{\omega}} + \int_{z_1}^{z_2} \frac{ds(z)}{d\widehat{\omega}} a(z)dz]}{(1-\rho)^2 L^2} \times \frac{\int_0^{\widehat{z}} b^*(z)dz}{\int_{\widehat{z}}^1 b(z)dz}. \tag{13}$$

Letting $\overline{\omega} \equiv \frac{a^*(z_1)}{a(z_1)}$, we define $\bar{s}(z)$ such that

$$\frac{1}{1 - \gamma(z)\bar{s}(z)} \frac{a^*(z)}{a(z)} = \overline{\omega}, \text{ or equivalently}$$

$$\bar{s}(z) = \frac{\overline{\omega} - a^*(z)/a(z)}{\overline{\omega}\gamma(z)}, \text{ for any } z \in [z_1, z_2].$$

Note that $s(z)$ is bounded, $s(z) \leq \bar{s}(z)$, for all $z \in [z_1, z_2]$. Under the assumption that z_1 is sufficiently close to $\widehat{z}_0$, the upper bound $\bar{s}(z)$ approaches zero, since its numerator, $\overline{\omega} - \frac{a^*(z)}{a(z)}$, has the maximum, $\frac{a^*(z_1)}{a(z_1)} - \frac{a^*(z_2)}{a(z_2)}$, and this maximum approaches zero. Under the assumption, we thus find that $s(z_2)$ approaches zero and that $s(z_1) = 0$ from the boundary conditions. The term $\int_{z_1}^{z_2} \frac{ds(z)}{d\widehat{\omega}} a(z)dz$ vanishes in the limit, since the change in $s(z)$ cannot exceed $\bar{s}(z)$

while $\bar{s}(z)$ and the integration interval $[z_1, z_2]$ approach zero. With $\widehat{\omega}$ held constant, the numerator of (12) becomes

$$\frac{\partial \Phi}{\partial \widehat{z}} = -\frac{L^*[s(z_2)a(z_2)\frac{dz_2}{d\widehat{z}} - s(z_1)a(z_1)\frac{dz_1}{d\widehat{z}} + \int_{z_1}^{z_2}\frac{ds(z)}{d\widehat{z}}a(z)dz]}{(1-\rho)^2L^2} \times \frac{\int_0^{\widehat{z}} b^*(z)dz}{\int_{\widehat{z}}^1 b(z)dz} - \frac{L^*}{(1-\rho)L}\frac{b^*(\widehat{z})\int_{\widehat{z}}^1 b(z)dz + b(\widehat{z})\int_0^{\widehat{z}} b^*(z)dz}{\left(\int_{\widehat{z}}^1 b(z)dz\right)^2}. \tag{14}$$

We can apply the same argument used in (13) to the first term in (14). Hence, returning to (12), we conclude that if z_1 is sufficiently close to $\widehat{z}_0$, then $\frac{d\widehat{\omega}}{d\widehat{z}} > 0$ since

$$\frac{d\widehat{\omega}}{d\widehat{z}} \to \frac{L^*}{L}\frac{b^*(\widehat{z}_0)\int_{\widehat{z}_0}^1 b(z)dz + b(\widehat{z}_0)\int_0^{\widehat{z}_0} b^*(z)dz}{\left(\int_{\widehat{z}_0}^1 b(z)dz\right)^2}. \tag{15}$$

In the second part, we verify beggar-thy-neighbor effects in three steps. First, using $\ln\widehat{\omega} = \ln\frac{L^*}{(1-\rho)L} + \ln\widehat{y}$, we rewrite (9) as

$$v - v_0 = [\ln\widehat{\omega} - \ln\widehat{\omega}_0]\int_{\widehat{z}_0}^1 b(z)dz + \ln(1-\rho) - \int_{z_1}^{\widehat{z}_0} b(z)\ln[1-\gamma(z)s(z)]dz + \int_{\widehat{z}_0}^{\widehat{z}} b(z)[\ln\alpha(z) - \ln\widehat{\omega}]dz. \tag{16}$$

Second, using (16), we calculate the marginal effect of extending $\widehat{z}$:

$$\frac{d(v-v_0)}{d\widehat{z}} = \frac{d\widehat{\omega}/d\widehat{z}}{\widehat{\omega}}\int_{\widehat{z}_0}^1 b(z)dz - \frac{d\rho/d\widehat{z}}{1-\rho} + \int_{z_1}^{\widehat{z}_0}\frac{b(z)\gamma(z)}{1-\gamma(z)s(z)}\frac{ds(z)}{d\widehat{z}}dz + b(z_1)(\ln[1-\gamma(z_1)s(z_1)])\frac{dz_1}{d\widehat{z}} + b(\widehat{z})[\ln\alpha(\widehat{z}) - \ln\widehat{\omega}] + \int_{\widehat{z}_0}^{\widehat{z}} b(z)\frac{d\alpha(z)/d\widehat{z}}{\alpha(z)}dz - \int_{\widehat{z}_0}^{\widehat{z}} b(z)\frac{d\widehat{\omega}/d\widehat{z}}{\widehat{\omega}}dz. \tag{17}$$

If z_1 is sufficiently close to $\widehat{z}_0$, the second term in (17) approaches zero since its numerator,

$$\frac{d\rho}{d\widehat{z}} = \frac{1}{L}[s(\widehat{z})a(\widehat{z}) - s(z_1)a(z_1)\frac{dz_1}{d\widehat{z}} + \int_{z_1}^{\widehat{z}}\frac{ds(z)}{d\widehat{z}}a(z)dz],$$

approaches zero in the limit, as we show in (14). By the same token, if z_1 is sufficiently close to $\widehat{z}_0$, the third term in (17) approaches zero. The fourth and fifth terms are zero given $s(z_1) = 0$ and $\alpha(\widehat{z}) = \widehat{\omega}$. The sixth term vanishes in the limit: the change in $\alpha(z)$ cannot exceed $\alpha(\widehat{z}_0) - \alpha(\widehat{z})$ on $[\widehat{z}_0, \widehat{z}]$ while $\alpha(\widehat{z}_0) - \alpha(\widehat{z})$ and the integration interval $[\widehat{z}_0, \widehat{z}]$ approach zero. The last term vanishes in the limit given the approximation of $\frac{d\widehat{\omega}}{d\widehat{z}}$ in (15). Hence, if z_1 is sufficiently close to $\widehat{z}_0$, then using (15) and $\widehat{\omega}_0$ in (8), we find that

$$\frac{d(v-v_0)}{d\widehat{z}} \to \left(\frac{b(\widehat{z}_0)}{\int_{\widehat{z}_0}^1 b(z)dz} + \frac{b^*(\widehat{z}_0)}{\int_0^{\widehat{z}_0} b^*(z)dz}\right)\int_{\widehat{z}_0}^1 b(z)dz.$$

Third, we use (10) and calculate the marginal effect on Foreign welfare:

$$\frac{d(v^*-v_0^*)}{d\widehat{z}} = -\frac{d\widehat{\omega}/d\widehat{z}}{\widehat{\omega}}\int_0^{\widehat{z}_0} b^*(z)dz + \int_{z_1}^{\widehat{z}_0}\frac{b^*(z)\gamma(z)}{1-\gamma(z)s(z)}\frac{ds(z)}{d\widehat{z}}dz + b^*(z_1)(\ln[1-\gamma(z_1)s(z_1)])\frac{dz_1}{d\widehat{z}} + b^*(\widehat{z})[\ln\alpha(\widehat{z}) - \ln\widehat{\omega}] + \int_{\widehat{z}_0}^{\widehat{z}} b^*(z)\frac{d\alpha(z)/d\widehat{z}}{\alpha(z)}dz - \int_{\widehat{z}_0}^{\widehat{z}} b^*(z)\frac{d\widehat{\omega}/d\widehat{z}}{\widehat{\omega}}dz.$$

We apply the same argument used above and find that if z_1 is sufficiently close to $\widehat{z}_0$, then

$$\frac{d(v^*-v_0^*)}{d\widehat{z}} \to -\left(\frac{b(\widehat{z}_0)}{\int_{\widehat{z}_0}^1 b(z)dz} + \frac{b^*(\widehat{z}_0)}{\int_0^{\widehat{z}_0} b^*(z)dz}\right)\int_0^{\widehat{z}_0} b^*(z)dz.$$

Hence, if z_1 is sufficiently close to $\widehat{z}_0$, then $v > v_0$ and $v^* < v_0^*$. ■

A.2. Proof of Proposition 2

Given $\widehat{z} \le \widehat{z}_0$, we consider two possible cases: (i) $\widehat{z} = \widehat{z}_0$ and (ii) $\widehat{z} < \widehat{z}_0$. The function $\alpha(z; s = 0)$ shifts to $\alpha(z)$ on the subsidy interval, and $\beta(z; s = 0)$ shifts to $\beta(z)$ on the entire interval $[0, 1]$. The case (i) occurs when $\alpha(z) \ge \beta(z)$ for all $z \in [0, \widehat{z}_0]$. The relative wage rises to $\widehat{\omega} = \beta(\widehat{z}_0) > \beta(\widehat{z}_0; s = 0) = \widehat{\omega}_0$. We calculate the welfare effects for (i):

$$v - v_0 = [\ln\widehat{\omega}_0 - \ln\widehat{\omega}]\int_0^{\widehat{z}_0} b(z)dz - \int_{z\in P} b(z)\ln[1-\gamma(z)s(z)]dz \text{ and}$$

$$v^* - v_0^* = [\ln\widehat{\omega}_0 - \ln\widehat{\omega}]\int_0^{\widehat{z}_0} b^*(z)dz - \int_{z\in P} b^*(z)\ln[1-\gamma(z)s(z)]dz.$$

The case (ii) occurs when $\alpha(z) < \beta(z)$ for some $z \in [0, \widehat{z}_0]$. The relative wage rises to $\widehat{\omega} = \beta(\widehat{z}) > \widehat{\omega}_0$. We find the welfare effects for (ii):

$$v - v_0 = [\ln\widehat{\omega}_0 - \ln\widehat{\omega}]\int_0^{\widehat{z}} b(z)dz - \int_{z\in P} b(z)\ln[1-\gamma(z)s(z)]dz + \int_{\widehat{z}}^{\widehat{z}_0} b(z)[\ln\widehat{\omega}_0 - \ln\frac{a^*(z)}{a(z)}]dz + \ln\widehat{y} - \ln\widehat{y}_0 \text{ and}$$

$$v^* - v_0^* = [\ln\widehat{\omega}_0 - \ln\widehat{\omega}]\int_0^{\widehat{z}} b^*(z)dz - \int_{z\in P} b^*(z)\ln[1-\gamma(z)s(z)]dz + \int_{\widehat{z}}^{\widehat{z}_0} b^*(z)[\ln\widehat{\omega}_0 - \ln\frac{a^*(z)}{a(z)}]dz.$$

From (i) and (ii), we obtain two findings. First, if $\gamma(z)$ is sufficiently large for $z \in P$ and P is sufficiently large, P approaches $[0, \widehat{z}_0]$. Without loss of generality, we focus on the extreme case where $P = [0, \widehat{z}_0]$, $\widehat{z} = \widehat{z}_0$, and $\widehat{y} = \widehat{y}_0$. Then $\alpha(z)$ shifts on $[0, \widehat{z}_0]$ with $\widehat{\omega} > \widehat{\omega}_0$,

$$\widehat{\omega} = \beta(\widehat{z}_0) = \frac{L^*}{L - \int_0^{\widehat{z}_0} s(z)a(z)dz}\frac{\int_0^{\widehat{z}_0} b^*(z)dz}{\int_{\widehat{z}_0}^1 b(z)dz} > \widehat{\omega}_0 = \beta(\widehat{z}_0; s = 0).$$

Note that $\beta(z)$ may shift such that $\alpha(\widehat{z}_0) > \beta(\widehat{z}_0) > \alpha(\widehat{z}_0; s = 0)$. Now, given $s(z)$, if $\gamma(z)$ is sufficiently large on $[0, \widehat{z}_0]$, the positive effects from the term

$$-\ln[1-\gamma(z)s(z)] = \ln\frac{1}{1-\gamma(z)s(z)}\frac{a^*(z)}{a(z)} - \ln\frac{a^*(z)}{a(z)} > 0,$$

dominate the negative effects from $\widehat{\omega} > \widehat{\omega}_0$ and thus $v > v_0$ and $v^* > v_0^*$. Second, if $b(z) = b^*(z)$ for all $z \in [0, \widehat{z}_0]$, then $v - v_0 \le v^* - v_0^*$, regardless of the signs of $v - v_0$ and $v^* - v_0^*$. ■

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