SOLUTIONS TO

Written Exam at the Department of Economics summer 2021

Economics of the Environment and Climate Change

Final Exam

June 10, 2021

(3-hour closed book exam)

Answers only in English.

This exam question consists of 5 pages in total, including this frontpage.

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SOLUTIONS TO

Written exam in the Economics of the Environment and Climate Change, Spring 2021

Question 1. Optimal environmental taxation in an economy with inequality (Indicative weight: ¾)

We consider an economy with two production sectors and two groups of workers, skilled and unskilled. The unskilled workers are employed in sector 1 producing good 1, while the skilled workers are employed in sector 2 producing another good 2. By working one hour an unskilled worker can produce one unit of good 1. The (exogenous) number of unskilled workers is n, and each unskilled worker works for ℓ hours, so the total output of good 1 is $n\ell$. Each unskilled person consumes the amount x_1 of good 1, while a skilled person consumes the amount X_1 of that good. The (exogenous) number of skilled workers is N, so the total consumption of good 1 is $nx_1 + NX_1$. Since total consumption must equal total output, we have the resource constraint

$$n\ell = nx_1 + NX_1. \qquad (1)$$

In sector 2 a skilled person can produce one unit of good 2 by working one hour. Each skilled person works for L hours, so the total output of good 2 is NL. An unskilled person consumes the amount x_2 of good 2, and a skilled person consumes the amount X_2 of that good, so by analogy to (1) we have the additional resource constraint

$$NL = nx_2 + NX_2. \qquad (2)$$

The preferences of an unskilled person are given by the utility function

$$u = \frac{x_1^{1-\eta_1}}{1-\eta_1} + \frac{x_2^{1-\eta_2}}{1-\eta_2} - \ell - aE, \qquad a > 0, \qquad \eta_1 \neq 1, \qquad \eta_2 \neq 1, \qquad (3)$$

where E is the emission of a pollutant, and the parameters η_1 and η_2 are the elasticities of the marginal utility of the two consumption goods. The presence of the term $-\ell$ in (3) reflects the disutility from work, and the term $-aE$ captures the negative welfare effect of pollution. Similarly, a skilled person has the utility function

$$U = \frac{X_1^{1-\eta_1}}{1-\eta_1} + \frac{X_2^{1-\eta_2}}{1-\eta_2} - L - bE, \qquad a > b > 0. \qquad (4)$$

The assumption $a > b$ reflects that the emissions of the pollutant are more damaging to the unskilled than to the skilled workers, say, because the unskilled live in neighbourhoods that are more exposed to pollution. Pollution is caused by the production and/or consumption of good 2, and we choose units such that the production/consumption of one unit of good 2 generates 1 unit of the pollutant. Since the total production/consumption of good 2 is $nx_2 + NX_2$, the total emissions are

$$E = nx_2 + NX_2. \tag{5}$$

Total social welfare SW is given by the utilitarian social welfare function

$$SW = nu + NU. \tag{6}$$

For the moment, we imagine that resource allocation is controlled by a benevolent social planner who maximizes the social welfare function (6) with respect to $x_1, x_2, \ell, X_1, X_2, L$ subject to the resource constraints (1) and (2). Using (1) through (6), we can write the Lagrangian $\mathcal{L}$ for this problem as

$$\mathcal{L} = n\left[\frac{x_1^{1-\eta_1}}{1-\eta_1} + \frac{x_2^{1-\eta_2}}{1-\eta_2} - \ell - a(nx_2 + NX_2)\right] + N\left[\frac{X_1^{1-\eta_1}}{1-\eta_1} + \frac{X_2^{1-\eta_2}}{1-\eta_2} - L - b(nx_2 + NX_2)\right]$$

$$+\lambda_1(n\ell - nx_1 - NX_1) + \lambda_2(NL - nx_2 - NX_2), \tag{7}$$

where λ_1 and λ_2 are Lagrange-multipliers associated with the two resource constraints.

Question 1.1: Derive the first-order conditions for the solution to the social planner's problem.

Answer to Question 1.1: From (7) we obtain the following first-order conditions:

$$\frac{\partial\mathcal{L}}{\partial x_1} = 0 \quad \Longrightarrow \quad x_1^{-\eta_1} = \lambda_1 \tag{i}$$

$$\frac{\partial\mathcal{L}}{\partial x_2} = 0 \quad \Longrightarrow \quad x_2^{-\eta_2} = \lambda_2 + an + bN \tag{ii}$$

$$\frac{\partial\mathcal{L}}{\partial \ell} = 0 \quad \Longrightarrow \quad \lambda_1 = 1 \tag{iii}$$

$$\frac{\partial\mathcal{L}}{\partial X_1} = 0 \quad \Longrightarrow \quad X_1^{-\eta_1} = \lambda_1 \tag{iv}$$

$$\frac{\partial\mathcal{L}}{\partial X_2} = 0 \quad \Longrightarrow \quad X_2^{-\eta_2} = \lambda_2 + an + bN \tag{v}$$

$$\frac{\partial\mathcal{L}}{\partial L} = 0 \quad \Longrightarrow \quad \lambda_2 = 1 \tag{vi}$$

(End of answer to Question 1.1).

Question 1.2: Show that the first-order conditions derived in Question 1.1 imply that the socially optimal resource allocation must satisfy the conditions

$$x_1 = X_1, \tag{8}$$

$$x_2 = X_2, \tag{9}$$

$$x_2^{-\eta_2} = X_2^{-\eta_2} = 1 + c, \qquad c \equiv an + bN. \tag{10}$$

Explain the economic intuition behind the conditions (8), (9), and (10).

Answer to Question 1.2: The first-order conditions (i) and (iv) imply that $x_1^{-\eta_1} = X_1^{-\eta_1}$ from which the result (8) immediately follows. Similarly, (ii) and (v) imply that $x_2^{-\eta_2} = X_2^{-\eta_2}$ which immediately leads to the result (9). Finally, when (vi) is inserted in the first-order conditions (ii) and (v), it follows directly that these two conditions can be stated in the form (10), given the definition of c. The economic intuition behind (8) and (9) is that a utilitarian social planner who wishes to maximize the sum of individual utilities will want to equalize the marginal utility of consumption across the two groups of workers, since this is a necessary condition for maximization of the sum of utilities. According to the utility functions (3) and (4) the two groups of workers obtain the same total and marginal utility from any given level of consumption of the two goods, so an equalization of their marginal utilities requires that all workers have the same level of consumption. The economic intuition behind (10) is that, in the social optimum, the marginal benefit (i.e., the marginal utility $x_2^{-\eta_2} = X_2^{-\eta_2}$) from consuming an extra unit of the polluting good 2 must equal the marginal social welfare loss from producing that good which is $1 + c$. Producing one more unit of good 2 requires one more hour of skilled work which generates a utility loss of one unit, since the utility function (4) implies that a skilled worker's marginal disutility of work is equal to 1. In addition, the production and/or consumption of one more unit of good 2 imposes an aggregate welfare loss equal to $a \cdot n$ on unskilled workers due to their increased exposure to pollution, plus an aggregate welfare cost of $b \cdot N$ for skilled workers due to the increase in pollution. Hence the total environmental welfare cost of producing/consuming an extra unit of good 2 is $c = an + bN$. Adding this to the marginal disutility from work, we end up with a marginal social cost equal to $1 + c$ from providing an extra unit of good 2. (*End of answer to Question 1.2*).

We now assume that resource allocation is not determined by a social planner, but by market mechanisms influenced by taxes and subsidies. The government imposes a unit tax at the rate t_1 on consumption of good 1 and a unit tax at the rate t_2 on consumption of good 2. To compensate for the relatively low wage of unskilled workers, the government also grants a wage supplement at the rate s per hour worked by an unskilled person. Finally, the government levies a uniform lump sum tax at the rate T per person to balance its budget. Hence the condition for a balanced government budget (the government budget constraint) is:

$$\overbrace{sn\ell}^{\substack{Expenditure\ on \\ wage\ supplement}} = \overbrace{t_1(nx_1 + NX_1) + t_2(nx_2 + NX_2)}^{Revenue\ from\ consumption\ taxes} + \overbrace{(n+N)T}^{\substack{Revenue\ from \\ lump\ sum\ tax}} . \tag{11}$$

The hourly wage rate for the unskilled workers employed in sector 1 is w, whereas the skilled workers employed in sector 2 earn the hourly wage $W > w$. Since it takes one hour of work to produce one unit of output in each sector, and labour is the only production factor, the marginal costs of production in sectors 1 and 2 are w and W, respectively. The firms in the two sectors are subject to perfect competition, so producer prices are equal to marginal costs. Hence the producer prices p_1 and p_2 in sectors 1 and 2 are $p_1 = w$ and $p_2 = W$, respectively, so in equilibrium firms earn zero profits. Accounting for consumption taxes and for the government wage supplement and the lump sum tax, the household budget constraint for an unskilled worker is

$$(p_1 + t_1)x_1 + (p_2 + t_2)x_2 = (w + s)\ell - T, \tag{12}$$

whereas the budget constraint for a skilled worker is

$$(p_1 + t_1)X_1 + (p_2 + t_2)X_2 = WL - T, \tag{13}$$

since skilled workers do not receive any wage supplement from the government.

Question 1.3: An unskilled worker maximizes her utility function (3) with respect to x_1, x_2 and ℓ subject to her budget constraint (12), taking prices, taxes, the net wage $(w + s)$ and the total emission level E as given. Set up the Lagrangian corresponding to the unskilled worker's maximization problem (denote the Lagrange multiplier associated with the budget constraint by λ^u) and show that the first-order conditions for the solution to the unskilled worker's problem imply that

$$x_1 = \left(\frac{p_1+t_1}{w+s}\right)^{-\frac{1}{\eta_1}}, \tag{14}$$

$$x_2 = \left(\frac{p_2+t_2}{w+s}\right)^{-\frac{1}{\eta_2}}. \tag{15}$$

Answer to Question 1.3: From the utility function (3) and the budget constraint (12) we get the following Lagrangian $\mathcal{L}^u$ corresponding to the unskilled worker's maximization problem:

$$\mathcal{L}^u = \frac{x_1^{1-\eta_1}}{1-\eta_1} + \frac{x_2^{1-\eta_2}}{1-\eta_2} - \ell - aE + \lambda^u[(w+s)\ell - T - (p_1+t_1)x_1 - (p_2+t_2)x_2] \tag{vii}$$

From (vii) we can derive the following first-order conditions for the solution to the unskilled worker's problem:

$$\frac{\partial \mathcal{L}^u}{\partial x_1} = 0 \quad \Longrightarrow \quad x_1^{-\eta_1} = \lambda^u(p_1 + t_1) \tag{viii}$$

$$\frac{\partial \mathcal{L}^u}{\partial x_2} = 0 \quad \Longrightarrow \quad x_2^{-\eta_2} = \lambda^u(p_2 + t_2) \tag{ix}$$

$$\frac{\partial \mathcal{L}^u}{\partial \ell} = 0 \quad \Longrightarrow \quad \lambda^u = \frac{1}{w+s} \tag{x}$$

Inserting (x) in (viii) and (ix), we get

$$x_1^{-\eta_1} = \frac{p_1 + t_1}{w + s} \quad \Leftrightarrow \quad x_1 = \left(\frac{p_1 + t_1}{w + s}\right)^{-\frac{1}{\eta_1}},$$

$$x_2^{-\eta_2} = \frac{p_2 + t_2}{w + s} \quad \Leftrightarrow \quad x_2 = \left(\frac{p_2 + t_2}{w + s}\right)^{-\frac{1}{\eta_2}},$$

which were the results (14) and (15) we were asked to derive. *(End of answer to Question 1.3).*

By following a procedure similar to the one in Question 1.3, one can show that a skilled person's utility-maximizing consumption levels are

$$X_1 = \left(\frac{p_1+t_1}{W}\right)^{-\frac{1}{\eta_1}}, \tag{16}$$

$$X_2 = \left(\frac{p_2+t_2}{W}\right)^{-\frac{1}{\eta_2}}. \tag{17}$$

Question 1.4: Use eqs. (14) through (17) to derive a formula for the wage supplement s and a formula for the consumption tax rate t_2 which will ensure that the market economy generates the socially optimal allocation satisfying eqs. (8), (9), and (10). (Hint: Remember that because of perfect competition, $p_2 = W$).

Answer to Question 1.4: From (14) through (17) we find that the socially optimal allocation can be implemented by setting

$$s = W - w \tag{xi}$$

$$t_2 = Wc \tag{xii}$$

Proof: Inserting (xi) in (14) and (15) and comparing the resulting equations with (16) and (17), we see that the wage supplement (xi) ensures that unskilled and skilled workers have exactly the same consumption of the two goods, thereby fulfilling conditions (8) and (9) for a social optimum. This is not surprising, since the wage supplement (xi) eliminates the difference between the net wage rates of unskilled and skilled workers. When formula (xi) for the wage supplement is inserted in (15), it also follows from (15) and (17) and the equilibrium condition $p_2 = W$ that

$$x^{-\eta_2} = X^{-\eta_2} = \frac{p_2+t_2}{W} = 1 + \frac{t_2}{W} \tag{xiii}$$

When t_2 is set in accordance with (xii), we see that the market relationship (xiii) will coincide with condition (10) for the socially optimal consumption of the polluting good 2. *(End of answer to Question 1.4).*

Question 1.5: Give an economic interpretation of (explain the intuition for) your formula for the optimal environmental tax rate t_2 derived in Question 1.4. (Hint: Utility maximization can be shown to imply that $\lambda^s = 1/W$, where λ^s is a skilled worker's marginal utility of income, i.e., the Lagrange multiplier associated with her budget constraint. Moreover, under the optimal policy we have $\lambda^u = \lambda^s$, where λ^u is an unskilled worker's marginal utility of income. Given these insights, what is an unskilled worker's marginal willingness to pay (MWTP) for a cut in pollution, measured in monetary units? And what is a skilled worker's MWTP?).

Answer to Question 1.5: When the net wages of the two groups of workers have been equalized through the wage supplement (xi), all workers have the same marginal utility of income $\lambda^u = \lambda^s = \lambda = 1/W$. The parameter a in the utility function (3) measures an unskilled worker's welfare loss from a one unit increase in pollution. When a is divided by the worker's marginal utility of income $\lambda = 1/W$, we get an unskilled worker's marginal willingness to pay for a one unit reduction in pollution expressed in monetary terms, $a/\lambda = aW$, so in total the group of unskilled workers will be willing to pay the amount naW to obtain a one unit cut in pollution. Similarly, we see from the utility function (4) that a skilled worker experiences a utility loss equal to b when pollution goes up by one unit, so in total the group of skilled workers will be willing to pay the amount $\frac{Nb}{\lambda} = NbW$ to obtain a one unit cut in emissions. Society's total marginal willingness to pay for a cut in pollution (MWTP$^{\text{total}}$) may therefore be written as

$$MWTP^{total} = \frac{na}{\lambda} + \frac{Nb}{\lambda} = W(na + Nb) = Wc \tag{xiv}$$

since $c \equiv an + bN$. The optimal tax rule (xii) requiring $t_2 = Wc$ therefore says that the tax rate on the polluting good 2 should equal the marginal external pollution cost created by the production and/or consumption of the good, where the marginal external cost is measured by summing the individual citizens' marginal willingness to pay for a cut in pollution. This is the standard Pigou rule for taxation of a polluting good which requires that the negative external cost of pollution be fully internalized via an environmental tax. *(End of answer to Question 1.5).*

Question 1.6: From an environmental viewpoint, or from a fiscal viewpoint, is there any reason why the government should choose to impose a tax t_1 on the consumption of good 1? Briefly motivate your answer.

Answer to Question 1.6: The answer to Question 1.4 shows that an appropriate choice of the policy instruments s and t_2 is sufficient to ensure an optimal allocation of resources, so from an environmental viewpoint there is no need for the policy instrument t_1. Moreover, the government budget constraint (11) shows that the government can balance its budget by adjusting the lump sum fiscal instrument T, so there is no fiscal motivation for imposing a tax on the non-polluting good either. Hence t_1 can be set equal to zero. This reflects that there is no environmental externality (pollution) associated with the production or consumption of good 1 and that a tax on good 1 is unnecessary to ensure that the government respects its budget constraint. Note from (15) and (17) that the demand for the dirty good 2 does not go up if the government imposes a tax t_1 on the clean good, reflecting that the cross price elasticities of demand are zero in this particular model. However, a tax on the clean good will distort the consumption of that good by causing substitution away from consumption of good x_1 towards consumption of leisure, thereby distorting labour supply. Therefore the government should not tax good x_1, given that it can redistribute income via the wage subsidy and given that it can raise the necessary revenue via the non-distortionary lump-sum tax. *(End of answer to Question 1.6).*

Question 1.7: Let $\bar{N} \equiv n + N$ denote the total population, assumed to be constant, and let α denote the share of unskilled workers in the total population so that $n = \alpha\bar{N}$ and $N = (1-\alpha)\bar{N}$. How does an increase in α affect the optimal environmental tax rate t_2? Explain. How is an increase in α likely to affect the optimal size of the wage supplement s? Explain (in verbal terms, you are not asked to undertake a mathematical analysis).

Answer to Question 1.7: Given the assumptions stated in Question 1.7, the total marginal willingness to pay for a cut in emissions specified in (xiv) can be restated as

$$MWTP^{total} = \frac{na}{\lambda} + \frac{Nb}{\lambda} = W(na + Nb) = W\bar{N}[\alpha a + (1-\alpha)b] \qquad \text{(xv)}$$

Since it is assumed in (4) that $a > b$, it follows from (xv) that an increase in α (the share of unskilled workers) will increase $MWTP^{total}$. As a consequence, the optimal tax rule $t_2 = MWTP^{total}$ therefore requires a higher tax rate rate on the polluting good, since emissions are now more harmful.

An increase in α implies an increase in the supply of unskilled workers and a lower supply of skilled workers. This will tend to reduce the equilibrium wage rate for the unskilled and to increase the equilibrium wage rate for skilled workers. However, the higher tax rate on the polluting good will dampen the demand for that good, thereby reducing the demand for the skilled labour which is used as an input in the production of good 2. If the fall in the demand for good 2 is large, it may imply that the demand for skilled workers falls by more than the fall in the supply of skilled labour, thereby reducing the equilibrium wage rate of skilled workers. Hence one cannot say for sure whether the optimal wage supplement $s = W - w$ for unskilled workers will increase or decrease. *(End of answer to Question 1.7).*

Question 1.8: Now suppose the government cannot implement a wage supplement, perhaps because it cannot observe the number of work hours of unskilled workers. Suppose further that the government does not have other policy instruments that can ensure an equalization of income distribution. Discuss briefly the considerations that are now relevant for the government's choice of the environmental tax rate t_2. Would the MWTP of the two groups of workers be given equal weight in the government's decision on the tax rate? And would the MWTP of the two groups of workers be the same? Explain.

Answer to Question 1.8: When the net wage rates cannot be equalized, unskilled workers will have a lower level of consumption and therefore a higher marginal utility of consumption than skilled workers. Specifically, it follows from (x) that an unskilled worker's marginal utility of income and consumption is $\lambda^u = 1/w$ when $s = 0$, so his marginal willingness to pay for a unit cut in pollution will be $MWTP^u = \frac{a}{\lambda^u} = wa$. By analogy, a skilled worker's marginal utility of consumption is $\lambda^s =$

$1/W$, so his marginal willingness to pay for a cut in pollution is $MWTP^s = \frac{a}{\lambda^s} = Wb$. Hence society's total marginal willingness to pay for a cut in pollution is

$$MWTP^{total} = nwa + NWb = \bar{N}[\alpha wa + (1-\alpha)Wb], \quad \text{(xvi)}$$

where we recall that α is the share of unskilled workers in the total population. Since $w < W$, we see by comparing (xv) to (xvi) that the total marginal willingness to pay is lower when there is no wage subsidy to unskilled workers (assuming plausibly that the general wage level does not rise significantly when $s = 0$). If the government continues to set the tax rate on the dirty good equal to the total marginal willingness to pay, it will therefore choose a lower environmental tax rate t_2 to account for the fact that unskilled workers are no longer willing to pay as much for lower pollution because they are now poorer. However, to compensate for the fact that it can no longer equalize the distribution of income, the government may want to assign a greater weight to the unskilled workers' marginal willingness to pay than their population share α. If the relative weight assigned to the *MWTP* of unskilled workers is $\beta > \alpha$, the expression for $MWTP^{total}$ changes from (xvi) to

$$MWTP^{total} = \bar{N}[\beta wa + (1-\beta)Wb]. \quad \text{(xvii)}$$

Since $w < W$ but $a > b$, and given the assumption that $\beta > \alpha$, it is not clear whether the expression for $MWTP^{total}$ in (xvii) is larger or smaller than the $MWTP^{total}$ implied by (xv). For example, if a is a lot higher than b, we could have $wa > Wb$, in which case a greater weight β assigned to the welfare of the unskilled workers would imply a higher pollution tax rate when $s = 0$ than when $s = W - w$. The intuition in this case is that when the government cannot directly redistribute income towards low-paid workers via a wage subsidy, it can instead redistribute welfare towards them by protecting them from pollution from which they suffer a lot.

Furthermore, one would have to carry out an explicit formal analysis to derive the exact formula for the optimal pollution tax rate in the second-best case where the government cannot implement a wage subsidy. This formula would not necessarily be identical to (xvi) or (xvii). Thus the general conclusion is that, although one would expect that the government will choose a lower pollution tax rate when it cannot use a wage subsidy, one cannot be sure that this will be the case. *(End of answer to Question 1.8. A satisfactory answer does not need to include equations like (xvi) and (xvii) as long as the verbal reasoning is clear).*

Question 2. Trade and the environment (Indicative weight: ¼)

Discuss the relationship between international trade and the quality of the environment. (*Note: This question may be answered without any use of math and/or graphical analysis. However, you are welcome to use math or diagrams to the extent that you find it convenient*).

Answer to Question 2: A natural starting point for answering this question is to restate the so-called Pollution Haven Hypothesis (PHH) which comes in two versions. According to the first version of the PHH, liberalization of trade or foreign investment causes pollution-intensive activities to relocate to countries with weaker environmental quality. According to the second version of the PHH, tightening pollution policy in one country causes pollution-intensive activities to relocate to other countries with weaker environmental policy.

In the curriculum, the validity of the first version of PHH is analyzed in a model where the world economy is divided into a rich Northern region and a poorer Southern region. Each region produces two tradable goods, a capital-intensive good and a labour-intensive good. Pollution (emissions) can be seen as an input in production in the sense that allowing higher emissions enables firms to increase their outputs. The governments in both regions impose an emissions tax in order to reduce emissions, since pollution harms consumer welfare. At any given pollution tax rate, production of a unit of the capital-intensive good generates more pollution than production of a unit of the labour-intensive good, which is empirically plausible. Before trade is liberalized, the North has a higher pollution tax rate than the South, because consumer (voter) demand for environmental protection is an increasing function of income, and income per capita is higher in the North than in the South.

When trade in goods is liberalized, the lower pollution tax rate tends to give the Southern region a comparative advantage in the production of the pollution-intensive capital-intensive good, thereby tending to shift some of the world production of this good in the direction of the South, as predicted by the first version of the PHH. But since rich countries are generally more capital-abundant, the higher capital/labour ratio in the rich North tends (seen in isolation) to give the Northern region a comparative advantage in production of the capital-intensive "dirty" good, thereby offsetting the comparative disadvantage arising from the relatively high pollution tax rate. Depending on the net effect of these offsetting impacts on comparative advantage, trade liberalization can either shift some of the production of the dirty good in the direction of the South or in the direction of the North. If the North ends up with a higher share of world production of the capital-intensive dirty good, the total global emissions will go down, because some of the world production of the pollution-intensive good is shifted to a region with stricter environmental regulation. This will happen if the North is very capital-abundant and/or if the North is not “too much” richer than the South and hence does not have a much higher pollution tax rate. This scenario shows that the Pollution Haven Hypothesis is not necessarily correct from a theoretical viewpoint: It is an empirical question whether the PHH holds. Empirical evidence suggests that when it comes to CO_2-emissions, the trade liberalization in recent decades has tended to shift some of the global emissions to the new emerging market economies, particularly China, which is in line with the PHH.

A good answer to Question 2 could also include a discussion of the effects of liberalizing international capital flows, given that trade has been liberalized. Before the introduction of capital mobility, firms in the North earn a lower rate of return on capital than firms in the South, due to the higher pollution tax rate in the North combined with the fact that firms in both regions sell their goods at the same world market prices. When capital flows are liberalized, capital will therefore flow from the North to the South in search of higher returns. This will allow the Southern government to collect pollution tax revenue from the Northern owners of imported capital, thereby raising income per capita in the South. As the South becomes richer in this way, Southern citizens will increase their demand for environmental protection, inducing the Southern government to increase its pollution tax rate. In principle Northern capital will continue to flow into the South until this process has resulted in a complete global equalization of the returns to capital and the tax rates on emissions. In the model described above one can show that complete liberalization of trade and capital flows will actually generate the same level of global emissions as a regime of complete autarky with no trade in goods and capital. Liberalization of capital flows will thus tend to eliminate any positive or negative effect of trade liberalization on pollution (given the strong assumptions of the model).

A good answer to Question 2 could also mention that environmental policy (the permitted level of emissions) can be used strategically by governments in an effort to shift profits from foreign to domestic firms operating in the same international market under conditions of imperfect competition. If firms engage in oligopolistic Cournot competition, taking the output of the competing firm(s) as given, one can show that each national government has an incentive to accept a higher level of emissions than the first-best socially optimal level in order to allow domestic firms to capture a larger share of the world market and thereby increase domestic profit income. This accords with a version of the PHH which says that international trade in goods will tend to cause a “race-to-the-bottom” in environmental policy standards. However, one can also show that if firms engage in oligopolistic Bertrand competition where each firm sets its price, taking the price of the competing firm(s) as given, national governments actually have a strategic incentive to *reduce* the permitted level of domestic emissions below the first-best optimal level where the marginal damage cost of pollution equals the marginal abatement cost, in contradiction to the prediction of a “race-to-the-bottom”. The reason is that, by reducing the permitted level of domestic pollution, thereby forcing the domestic firm to raise its price due to higher marginal abatement costs, the domestic government can also induce the firm’s foreign competitor to raise its price. This reaction of the foreign firm helps to preserve the competitiveness of the domestic firm, making it more attractive for the domestic government to tighten the environmental standard. The foreign government has the same strategic incentive, so in an international equilibrium both countries will choose to push the marginal abatement cost above the marginal damage cost of pollution.

An answer to Question 2 can also include a graphical partial equilibrium analysis of the second version of the PHH mentioned above, illustrating how a tightening of domestic environmental standards affects world pollution. This can be done by using diagrams like figures 4, 5 and 6 in Lecture 11 in the curriculum.

Finally, an answer to Question 2 may include a reference to the Porter Hypothesis which comes in a “weak” and in a “strong” version. The weak version says that the direct static effects of environmental regulation on domestic production costs may be partly offset by induced technical progress and elimination of unnecessary waste, as firms are induced to find new ways of reducing their emissions. The strong version of the Porter hypothesis says that environmental regulation may actually improve the international competiveness of domestic firms by making them more innovative. In both versions environmental regulation is assumed to be “intelligent”, meaning that it is flexible and oriented towards the use of cost-effective market-based policy instruments like emission taxes or tradable emission permits. The empirical evidence has given some support to the weak version of the Porter Hypothesis, but not to the strong version.

(Comment: Due to the time constraint, an answer to Question 2 cannot be expected to include all of the above elements, at least not at the level of detail described here. Hence it is possible to obtain a good grade even if the answer to Question 2 leaves out some of the elements mentioned above).