Free Trade Agreements and the Environment with Pre-existing Subsidies*

Claustre Bajona
Department of Economics
University of Miami
Box 248126
Coral Gables, FL 33124
cbajona@miami.edu

and

David L. Kelly
Department of Economics
University of Miami
Box 248126
Coral Gables, FL 33124
dkelly@miami.edu

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PRELIMINARY

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Abstract

Countries that wish to erect trade barriers have a variety of instruments at their disposal. In addition to tariffs and quotas, countries can offer tax relief, low interest financing, reduced regulation, and other subsidies to domestic industries facing foreign competition. In a trade agreement, countries typically agree to reduce not only tariffs, but also subsidies. We consider the effect of a trade agreement on pollution emissions. We show that while reducing tariffs may indeed increase pollution intensive production in a country, reductions in some subsides required by the trade agreement reduce pollution in general equilibrium for reasonable parameter values. The reduction results from two effects. First, a reduction in subsidies to firms reduces pollution-causing capital accumulation. Second, if subsidized firms, industries, and/or state owned enterprises are sufficiently more pollution intensive, then reducing subsides moves capital and labor from more to less pollution intensive firms. We then calibrate the model to China in 1997, which is prior to implementing the reforms specifically required by the US-China World Trade Organization (WTO) Bilateral Agreement. Our model predicts that pollution emissions in China are up to 22.9% lower than a baseline in which China does not enter the WTO, without any pollution abatement policy changes or environmental side agreements.

1 Introduction

Countries that wish to erect trade barriers have a variety of instruments at their disposal. In addition to tariffs and quotas, countries can offer tax relief, low interest financing, reduced regulation, and other subsidies to domestic industries facing foreign competition. The political process is unlikely to produce a uniform tariff. Instead, countries with high trade barriers employ a complex mixture of all these instruments, resulting in significant distortions. In a trade agreement, countries typically agree to reduce not only tariffs, but also subsidies. For example, subsidies to exporting industries violate WTO rules.[1]

The main claim of our paper is that reductions in domestic subsidies implied by some trade agreements have significant effects on pollution emissions. These effects are associated with a country's opening to trade and, therefore, cannot be ignored when considering the effects of trade agreements on pollution. Indeed, we give conditions for which reducing subsidies to comply with a trade agreement causes pollution to fall. The pollution reduction results from two effects. First, a reduction in subsidies to industry reduces pollution-causing capital accumulation. Second, if heavily subsidized firms, industries, and/or state owned enterprises (SOEs) are sufficiently more pollution intensive, then reducing subsides moves capital and labor from more to less pollution intensive firms.

Empirical evidence exists which shows our conditions are reasonable. Wang and Jin (2002) find that SOEs in China are more pollution intensive (by up to a factor of 10). Wang, Mamingi, Laplante, and Dasgupta (2002) find that one reason is that large, politically connected SOEs enjoy lax enforcement of environmental regulations. In our most conservative calibration, our main condition is satisfied for three of four pollutants studied by Wang and Jin (2002).

Thus even if world tariff reductions cause pollution-intensive production to increase in a country, overall pollution may still fall because the tariff effect is more than offset by the reduction in pollution caused by the reduction in subsidies. Indeed, we calibrate the model

[1]Specifically, subsides specific to an individual or group of firms, products, or industries which are either contingent on export performance ("prohibited") or have adverse effects on member industries ("actionable") are not allowed. Member countries may bring suit to have such subsidies removed or be allowed to retaliate. See Annex 1A, Agreement on Subsidies and Countervailing Measures of the WTO's legal document on the Uruguay Round Agreements.

to China in 1997 and find that, after reducing subsidies required by the WTO agreement, the equilibrium path of total suspended particulates (TSP) in our model converges over time to a steady state 17.6% lower than a baseline economy in which no subsidies are reduced. Similarly, steady state chemical oxygen demand (COD) is 7.6% lower, and sulfur dioxide (SO_2) is 22.9% lower (total suspended solids, TSS, rise by 0.5%). The reduction in pollution occurs without any environmental side agreements or abatement policy changes.

There is a large theoretical literature on free trade and the environment.[2] Following Copeland and Taylor (2004) and others, we denote the idea that a reduction in trade barriers causes pollution intensive production to shift from countries with relatively stringent regulation to countries with relatively weak regulation the *pollution haven hypothesis*.[3] A competing theory, the *factor endowment hypothesis* says that since pollution is capital intensive, reducing trade barriers should cause pollution intensive industries to move to the more capital intensive country, usually the more developed country.

Antweiler, Copeland, and Taylor (2001) decompose the effect of reducing trade barriers on pollution into scale, composition, and technique effects familiar from the Environmental Kuznets Curve literature (Grossman and Krueger 1995). Reducing trade barriers causes output to rise, which increases pollution (the scale effect). However, the increase in income also results in increased abatement spending, reducing pollution (the technique effect). Finally, a reduction in trade frictions causes the country exporting the dirty good to specialize in that good, increasing pollution (the composition effect).

Our results can be interpreted in a similar way. As in Antweiler, Copeland, and Taylor (2001), a scale effect exists in that reducing in trade barriers causes output to rise, which increases pollution. Our model by assumption has no changes in abatement policy. Yet if subsidies fall we still have technique effect. If subsidized firms are more pollution intensive, then when production moves from the subsidized sector to the private sector, overall pollution intensity falls. Our technique and scale effect can be combined into a relatively simple criteria that determines whether or not pollution will rise or fall as subsidies fall. Our calibration to

[2]Survey papers include Kolstad and Xing (1996), Rauscher (2001), and Ulph (1997).

[3]That is, we are not considering the *pollution haven effect*, which deals with the effect of pollution regulations on trade flows.

China indicates this criteria is reasonable and indicates the technique effect is quite strong in practice.

The literature on how subsidies to industry affect the environment is very sparse.[4] Since almost all countries have industrial policies which favor some industries, this lack of attention is quite surprising. To understand pollution in such a setting requires a theory of firms and industry structure in such economies. Bajona and Chu (2005) provide such a theory, which we use here. Their industry structure consists of a private firm and a subsidized firm, which they interpret as an SOE, perhaps facing foreign competition. Subsidized firms have restrictions on the number of people they can lay off (Yin 2001), which we model as a minimum labor requirement. In exchange, subsidized firms receive low interest loans from the government or state owned banks (modeled as an interest rate subsidy) and receive direct subsidies to cover the negative profits that result from the use of an inefficient mix of capital and labor. Finally, subsidized firms have lower total factor productivity (TFP) relative to private sector firms. Thus, subsidized firms and private firms co-exist in equilibrium with the share of production of subsidized firms determined endogenously by the subsidies, labor requirements, and technology difference.

Although the literature on subsidies and the environment is sparse, there is a related empirical literature on SOEs and the environment. Wang and Jin (2002) find SOEs in China are more pollution intensive than private firms. In addition, Gupta and Saksena (2002) find that SOEs in India are monitored for environmental compliance less often than private firms. Wang, Mamingi, Laplante, and Dasgupta (2002) find that SOEs in China enjoy more bargaining power over environmental compliance than private firms. Galiani, Gertler, and Schargrodsky (2005) find that privatization of water services in Argentina improved health outcomes. However, Earnhart and Lizal (2002) find an inverse relationship between pollution intensity and percentage of state ownership among recently partially privatized firms in the Czech Republic in their preferred model. The latter two studies focus on a change in ownership, which does not necessarily imply a change in subsidies.[5]

[4]The only literature is on agricultural subsidies and the environment, see for example Antle, Lekakis, and Zanias (1998).

[5]It is well known that recently privatized SOEs retain a close relationship to the state and thus possibly their subsidies. A trade agreement is thus different than privatization in that the former reduces subsidies,

We derive two conditions from several offsetting effects that subsidies have on pollution. The first condition determines the effect of a reallocation of resources caused by subsidies on pollution, which we call *capital and labor resource reallocation effects.* First, direct subsidies raise equilibrium employment in subsidized firms, causing output to become more concentrated in subsidized firms. Second, the increase in employment causes capital to flow to the subsidized sector, further concentrating output in subsidized firms. If subsidized firms are more pollution intensive, these two effects cause pollution to increase. The third offsetting effect is that in equilibrium the marginal product of labor and capital are lower in the subsidized sector. Thus direct subsidies reduce overall output and pollution by concentrating labor and capital in the low-productivity subsidized sector. Our main condition requires the first two effects to be stronger.

In addition to the reallocation of resources, a *capital accumulation effect* exists in that subsidies to firms directly increase overall demand for capital. However, the decline in overall productivity caused by the concentration of capital in the subsidized sector tends to reduce demand for capital. We show that the former effect is stronger so the return to capital rises, causing the economy to over-accumulate capital, which causes pollution to rise over time with subsidies.

Our results are also useful for the empirical literature on trade and the environment. Mani and Wheeler (1997), Low and Yeats (1992), Ratnayake (1998), and others find some evidence in favor of the pollution haven hypothesis. These studies suffer from lack of pollution data in less developed countries, and so must instead classify industries according to their emissions intensity in the US and then correlate output in pollution intensive industries to openness. Our results show that indeed output in the dirty industry may rise following a reduction in tariffs or subsidies, but because the reduction in subsidies causes production to shift to the less pollution intensive private sector, overall (unmeasured) pollution may still fall.[6]

Our theoretical results are consistent with the empirical results of Birdsall and Wheeler (1992) and Lucas, Wheeler, and Hettige (1992), who find that pollution intensity is rel-

while the latter changes ownership.

[6]Copeland and Taylor (2004) discuss other possible cases where output rises but pollution falls as countries reduce trade barriers.

atively lower in more open economies. Our model suggests that the reason is that trade agreements reduce subsidies to pollution intensive subsidized firms. These empirical results are sometimes viewed as evidence against the pollution haven hypothesis, but our results show that it is possible that a reduction in tariffs causes an increase in production of the dirty good (the pollution haven hypothesis), but at the same time the reduction in subsidies causes the overall pollution intensity to fall as production moves from dirty subsidized firms to the cleaner private sector (consistent with more open countries having lower pollution intensity). Antweiler, Copeland, and Taylor (2001) avoid these data problems by using data on sulfur dioxide emissions from the Global Environmental Monitoring database. They also find a surprisingly strong technique effect, which is consistent with our numerical results that reductions in subsidies results in a very strong technique effect.

2 A Theory of Pollution, Subsidies, and Trade

In this section, we consider a simplified version of the model in Bajona and Chu (2005) with different pollution intensities for private and subsidized firms in order to derive some analytic results on how subsidies affect pollution emissions. As such, the model is of independent value as it provides a theory of pollution and industrial policy.

2.1 Firms

Private and subsidized firms differ in four aspects: productivity, pollution intensity, ability to choose their labor input, and cost of capital. Productivity differences are taken as exogenous, with subsidized firms having TFP equal to A_G, while private firms have TFP equal to A_P. Private and subsidized firms have access to the same constant returns to scale technology F.

We assume that subsidized firms are subject to a labor requirement equal to l_G established by the government. In exchange for keeping the level of employment, the government covers any losses through direct subsidies. Given a binding labor constraint, subsidized firms use an inefficient mix of capital and labor and the earn negative profits. Subsidized and private firms then co-exist if subsidized firms receive enough direct cash subsidies from the government to earn zero profits.[7] Therefore, let $S = -\pi_G$ be the direct subsidy, where π_G are the (negative) profits of subsidized firms excluding the direct subsidy and $\Pi_G = \pi_G + S = 0$ are the profits including the direct subsidy. To save on notation, we suppress the time t subscripts where no confusion is possible.

Let l_P be the labor demand of the private sector. The representative household is endowed with one unit of labor every period, which is supplied inelastically. Therefore, in equilibrium $l_G + l_P = 1$.

Subsidized firms receive a second subsidy, a discount on their rental rate of capital, which we call an interest subsidy. If we denote the rental rate of capital for private firms as r (in terms of domestic goods), the rental rate of capital for subsidized firms is $(1 - s)r$, where s is the subsidy rate. This subsidy can be interpreted as either the government guaranteeing repayment of funds borrowed by subsidized firms, SOEs borrowing at the government's rate of interest, or as the government steering household deposits at state owned banks to subsidized firms at reduced interest rates.[8]

The objective of both private and subsidized firms is to maximize profits taking prices and government policies as given. If the subsidized firm is privately owned, then profit maximization is clearly reasonable. But even if the subsidized firm is state owned, evidence exists for the idea that managers of SOEs are given incentives consistent with profit maximization.[9] Our theory is not based on differences in firm ownership, since whether households or firms own the capital is irrelevant as long as all firms maximize profits. Instead, our theory is based on the subsidies that firms with a close relationship to the state enjoy.

The problem of a subsidized firm consists of maximizing profits subject to the labor requirement imposed by the government and the subsidy on capital:

$$\pi_G = \max_{K_G} A_G F(K_G, l_G) - (1 - s) r K_G - w l_G. \tag{2.1}$$

[7] In the absence of subsidies, in a competitive equilibrium only the firm with the highest TFP operates.

[8] The latter interpretation is more reasonable for developing countries. All three interpretations are consistent with households renting capital.

[9] For China, Yin (2001) assume SOEs maximize profits, based on the results from Choe and Yin (2000). However, we are ignoring agency issues and other problems associated with SOEs (see for example Gupta 2005, Shleifer and Vishny 1994).

Here K_G and K_P are the parts of aggregate capital allocated to the subsidized and private sectors, respectively, and $K = K_G + K_P$ is the aggregate capital stock per person. Let subscripts on functions denote partial derivatives. The first order condition which determines the part of the capital stock allocated to the subsidized sector is:

$$(1 - s) r = A_P F_k (K_G, l_G) . \tag{2.2}$$

The problem for private firms is standard:

$$\pi_P = \max_{K_P, l_P} A_P F (K_P, l_P) - r K_P - w l_P. \tag{2.3}$$

The equilibrium rental rate and wage rate, w (also in domestic goods), are:

$$r = A_P F_k (K - K_G, 1 - l_G) , \tag{2.4}$$

$$w = A_P F_l (K - K_G, 1 - l_G) . \tag{2.5}$$

Let F be constant returns to scale in K and l, have positive and diminishing marginal products, satisfy $F(0, l) = F(K, 0) = 0$, and satisfy the Inada conditions in each input. Then equations (2.2), (2.4), and (2.5) have a unique solution $K_G (K, A_G/A_P (1 - s) , l_G)$, $r (K, A_G/A_P (1 - s) , l_G)$, and $w (K, A_G/A_P (1 - s) , l_G)$. The labor constraint is binding (subsidized firms hire more labor than is efficient) if and only if $w > A_G F_l (K_G, l_G)$. If subsidized firms hire less labor than is efficient, they make positive profits and the direct subsidy is a tax. Since this case is not interesting, we assume the constraint binds. A sufficient condition for the constraint to bind is:[10]

$$(1 - s) A_P > A_G. \tag{2.6}$$

[10]For a Cobb-Douglas production function, $w > A_G F_l (K_G, l_G)$ if and only if $(1 - s)^{\alpha} A_P > A_G$, where α is the capital share.

We can also show:

$$0 < \frac{\partial K_G}{\partial K} < 1 \ , \ \frac{\partial K_G}{\partial s} \ , \ \frac{\partial K_G}{\partial l_G} > 0, \tag{2.7}$$

$$\frac{\partial r}{\partial K} \ , \ \frac{\partial r}{\partial l_G} < 0 \ \Leftrightarrow \ \text{condition (2.6)}, \ \ \frac{\partial r}{\partial s} > 0, \tag{2.8}$$

$$\frac{\partial w}{\partial K} > 0, \ \ \frac{\partial w}{\partial s} > 0 \ , \ \frac{\partial w}{\partial l_G} > 0 \ \Leftrightarrow \ \text{condition (2.6)}. \tag{2.9}$$

Apparently, a decrease in the interest subsidy rate implies a reallocation of capital from the subsidized sector to the private sector. Further, a decrease in the interest subsidy rate decreases the total demand for capital, hence the interest rate must fall to bring demand for capital back up to the supply. Similarly, a fall in the demand for capital implies a lower demand for labor as well so the wage rate must also fall. This simple intuition drives many of the results in the paper. Although a fall in the labor requirement will cause labor to move from the subsidized sector the private sector by definition, it is not immediate that the wage rate falls. Instead, the fall in the labor requirement causes the subsidized sector to reduce demand for capital as well. If the private sector sees sufficiently little increase in capital relative to the increase in labor, wages fall, but it could be that a large change in capital in the private sector causes demand for labor to rise, pushing up wages. The overall effect depends on the relative TFP of the two sectors.

Finally, the share of capital allocated to the subsidized sector adjusts to equate the after-subsidy returns in the two sectors. If the interest subsidy rises, capital flows to the subsidized sector, reducing the marginal product of capital in that sector and increasing the marginal product of capital in the private sector until the after-subsidy returns are equated. Thus, the equation which governs the fraction of capital allocated to the subsidized sector is:

$$(1 - s) \, A_P F_k \left(K - K_G, 1 - l_G \right) = A_G F_k \left(K_G, l_G \right). \tag{2.10}$$

2.2 Households

2.2.1 Aggregate Good

Households enjoy consumption of an aggregate good c, which is a composite of the domestic produced good, X, and the imported good, M. Let $u(c)$ denote the per period utility, which we assume is strictly increasing and concave, twice-continuously differentiable, and satisfies the Inada conditions. The objective of households is:

$$\max \sum_{t=0}^{\infty} \beta^t u(c_t) \tag{2.11}$$

Let X_D denote the part of domestic production that is consumed domestically, and X_F denote the part of domestic production that is consumed abroad. Households use an Armington aggregator to combine X_D domestic goods and M foreign goods into Y_C aggregate goods:[11]

$$Y_C = X_D^{\mu} M^{1-\mu}. \tag{2.12}$$

We can interpret μ as the share of domestic production consumed domestically, absent domestic tariffs. The composite good can also be used for investment. Let primes denote next period's value, and δ the depreciation rate, then the aggregate resource constraint is:

$$Y_C = C + K' - (1-\delta) K \tag{2.13}$$

Households use an efficient mix of X_D and M to form the aggregate good. Let p_c denote the price of the aggregate good, p_D denote the price of the good produced domestically, and $p_w(1+\tau_D)$ denote the domestic price of the imported good, where τ_D is a tariff and p_w is the world price, normalized to one. Hence, p_c and p_D are the price of the aggregate and domestic good in terms of world goods, respectively.

Efficiency requires the marginal contribution of the inputs of the aggregate good equal

[11] The Armington aggregator assumption is made in order to be able to match trade data. In order to simplify the analytical derivations, we assume that the aggregator is a Cobb-Douglas function. In the computational model, we assume the aggregator is a more realistic CES function. The results are very similar to the theoretical model.

their prices:

$$\mu p_c X_D^{\mu-1} M^{1-\mu} = p_D, \tag{2.14}$$

$$(1-\mu)\, p_c X_D^{\mu} M^{-\mu} = 1 + \tau_D. \tag{2.15}$$

Hence the marginal rate of technical substitution equals the price ratio:

$$\frac{1-\mu}{\mu}\frac{X_D}{M} = \frac{1+\tau_D}{p_D}. \tag{2.16}$$

2.2.2 Trade

We assume an exogenous foreign demand curve for domestically produced goods. Let τ denote the world tariff on domestic production, then:

$$X_F = \hat{D}\left(p_D\left(1+\tau_F\right)\right)^{\frac{-1}{1-\zeta}}. \tag{2.17}$$

Here $\frac{-\mu}{1-\mu} < \zeta < 1$. If foreigners also use a Cobb-Douglas Armington aggregator, the elasticity of substitution is one or $\zeta = 0$. Let $D \equiv \hat{D}\left(1+\tau_F\right)^{\frac{-1}{1-\zeta}}$, then:

$$X_F = D p_D^{\frac{-1}{1-\zeta}}. \tag{2.18}$$

In this section we assume capital markets are closed.[12] Since capital markets are closed, trade in goods must balance:

$$M = p_D X_F. \tag{2.19}$$

2.3 Government

The government budget is balanced by including a lump sum transfer, TR. Thus the government budget constraint sets interest plus direct subsidies equal to lump sum taxes plus

[12] This is reasonable for many countries, but obviously not for all. We allowed capital markets to open in the computational model, and the results did not change much.

tariff revenue $TF \equiv \tau_D M$:

$$srK_G + S = -TR + TF. \tag{2.20}$$

It is straightforward to show that the direct subsidies equal total wage payments less the total product of labor, that is, direct subsidies equal the total cost of the hiring constraint. Hence:

$$srK_G + \left(w - A_G F_h\left(K_G, l_G\right)\right) l_G = -TR + TF. \tag{2.21}$$

2.4 Market Clearing

Market clearing requires demand for domestic goods to equal domestic production, Y:

$$X_D + X_F = Y. \tag{2.22}$$

Further, domestic production must equal income from factor payments plus transfers:

$$Y = \frac{1}{p_D}\left(rK + w + TR\right). \tag{2.23}$$

2.5 Pollution

We assume emissions of a flow pollutant, P, is proportional to domestic production. Let σ denote the emissions intensity of output. Then:

$$P = \sigma_G Y_G + \sigma_P Y_P. \tag{2.24}$$

Here Y_G and Y_P are subsidized and private production, respectively. No abatement technology exists, so pollution falls only by reducing output or by moving production to the less pollution intensive sector.[13] Given that the private and subsidized sectors are at different technology levels, it is reasonable to assume that they also have different pollution intensities.

[13] We do not include abatement as we wish to focus on the direct effect of subsidies on pollution. If abatement was included, and if abatement increased with income, then this would only strengthen our conclusions.

We can write total pollution as a fraction of total output in the following way:

$$P = \sigma Y, \tag{2.25}$$

where Y is total output and σ is the economy wide emissions intensity:

$$\sigma \equiv \frac{\sigma_G Y_G + \sigma_P Y_P}{Y}, \quad Y \equiv Y_G + Y_P. \tag{2.26}$$

3 Theoretical Results

To characterize the equilibrium, we substitute out for the firm and trade variables so as to write the model as a single capital accumulation problem. Equations (2.16), (2.18), and (2.19) imply the domestic demand curve is:

$$X_D = \frac{\mu}{1-\mu} D\left(1+\tau_D\right) p_D^{\frac{-1}{1-\zeta}}. \tag{3.1}$$

To find the domestic price, we can substitute the foreign demand curve (2.18) and the domestic demand curve (3.1) into the market clearing condition (2.22), to get:

$$p_D = \left(\frac{D}{\left(1-\psi\right)Y}\right)^{1-\zeta}, \quad \psi \equiv \frac{\mu\left(1+\tau_D\right)}{1+\mu\tau_D}. \tag{3.2}$$

Hence:

$$X_D = \psi Y, \tag{3.3}$$

$$X_F = \left(1-\psi\right)Y, \tag{3.4}$$

$$M = D^{1-\zeta}\left(\left(1-\psi\right)Y\right)^{\zeta}. \tag{3.5}$$

Note that ψ is the share of domestic output consumed domestically, with $\psi = \mu$ if $\tau_D = 0$. Finally, substituting the demand functions into the aggregate resource constraint implies:

$$C + K' - \left(1-\delta\right)K = \Omega Y^{\phi}, \tag{3.6}$$

$$\Omega \equiv \psi^{\mu} (1-\psi)^{\zeta(1-\mu)} D^{(1-\mu)(1-\zeta)}, \tag{3.7}$$

$$\phi \equiv \mu + \zeta (1-\mu). \tag{3.8}$$

Here $\phi = \mu$ and $\Omega = \psi^{\mu} D^{(1-\mu)}$ if foreigners use a Cobb-Douglas Armington Aggregator. The resource constraint (3.6) shows how foreign demand affects resources available for aggregate consumption or investment. Note that under our maintained assumptions, $\phi \in (0,1)$.

Let k denote the capital stock of an individual, then the recursive household problem is:

$$\begin{aligned} v(k,K) \;\; = \;\; & \max_{k'} \Big\{ u \Big[\Omega \left(r(K;s;l_G)\, k + w(K;s;l_G) + TR(K;s;l_G) \right)^{\phi} - k' + \\ & (1-\delta)\, k \Big] + \beta v(k', K') \Big\}. \end{aligned} \tag{3.9}$$

We characterize the model by establishing the existence and properties of the equilibrium.

Definition 1 *A Recursive Competitive Equilibrium given individual and aggregate capital stocks k and K and government policies $\{\tau_F,\, \tau_D,\, s,\, l_G\}$ is a set of individual household decisions $\{c,\, k'\}$, trade decisions $\{X_D,\, X_F,\, M\}$, prices $\{r,\, w,\, p_D,\, p_c\}$, aggregate household decisions $\{C,\, K'\}$, a subsidized firm input decision K_G, private firm input decisions $\{K_P,\, l_P\}$, government variables $\{S,\, TR\}$, and a value function v such that the household's and producers' (private and subsidized) problems are satisfied, all markets clear, subsidized firms earn zero profits, the government budget constraint is satisfied, and the consistency conditions ($k = K$ implies $c = C$ and $k' = K'$) are satisfied.*

Capital accumulation is then determined from the equilibrium first order condition and envelope equation:

$$u_c(C(K;s;l_G)) = \beta v_k(K', K') \tag{3.10}$$

$$v_k(K,K) = u_c(C(K;s;l_G)) \left(\phi \Omega Y(K;s;l_G)^{\phi-1} r(K;s;l_G) + 1 - \delta \right) \tag{3.11}$$

$$C(K;s;l_G) = \Omega Y(K;s;l_G)^{\phi} - K' + (1-\delta) K \tag{3.12}$$

$$Y(K;s;l_G) = A_P F(K - K_G(K;s;l_G), 1 - l_G) + A_G F(K_G(K;s;l_G), l_G) \tag{3.13}$$

Our strategy is to establish some basic properties of the competitive equilibrium, and then use these properties to derive the more complicated results on how pollution changes with changes in subsidies.

THEOREM 1 *Suppose u and F are as described above. Then a competitive equilibrium exists. Further, the equilibrium gross investment function $K' = H(K)$ is such that:*

1. $H_K(K) \geq 0$,
2. $C_K(K) \geq 0$,
3. $H(K)$ *satisfies the Euler equation derived from (3.10) and (3.11), and*
4. $H(K)$ *is concave.*

All proofs are in the Appendix.

A trade agreement often consists of a combination of reductions in tariffs and subsidies to domestic enterprises. In order to derive intuition on the effect of each type of government subsidy, we consider each one in isolation. In particular, we consider a reduction in interest subsidies leaving the labor requirement unchanged (notice that this increases the losses made by subsidized firms and, thus, the direct subsidies), a reduction in direct subsidies, where the labor requirement is reduced so that interest subsidies are kept constant, and a reduction in both interest and direct subsidies (achieved through a reduction in the labor requirement).

3.1 The Effect of Reducing Interest Subsidies

Consider first a reduction in the interest subsidy rate to firms, holding the labor requirement fixed. According to the industrial structure described above, direct subsidies must rise so that subsidized firms continue to earn zero profits. Differentiating the pollution accumulation equation (2.24) with respect to s gives:

$$\frac{\partial P}{\partial s} = \sigma_G \left(A_G F_k(K_G, l_G) \frac{\partial K_G}{\partial s} \right) - \sigma_P \left(A_P F_k(K - K_G, 1 - l_G) \frac{\partial K_G}{\partial s} \right). \tag{3.14}$$

Equation (2.10) implies the after-subsidy marginal products are equal. Hence:

$$= (\sigma_G (1 - s) - \sigma_P) \, r(K) \frac{\partial K_G}{\partial s} \tag{3.15}$$

Equation (2.7) implies current period pollution is increasing in the subsidy if and only if:

$$\frac{\sigma_G}{\sigma_P} > \frac{1}{1 - s} \tag{3.16}$$

From equation (3.14), a decrease in the interest subsidy causes capital to flow from the more pollution intensive government sector to the less pollution intensive private sector, reducing pollution. However, due to the subsidy the private sector has a higher marginal product of capital, so output rises as capital flows to the private sector. It follows that for overall pollution emissions to fall, the ratio of emissions intensities must be greater than the ratio of marginal products, which equals $\frac{1}{1-s}$. Changes in the lump sum direct subsidy do not affect the equilibrium allocations.

In addition to the static effect, a decrease in interest subsidies has a dynamic effect on pollution through changes in the path of capital accumulation.

THEOREM 2 *Let F and u be as described above, $\sigma_G > \sigma_P$, and suppose a decrease in s holding l_G fixed. Let $K_0 = \bar{K}$. Then:*

1. *The economy transitions to a new steady state $\left(\bar{\bar{K}}, \bar{\bar{P}}\right)$ with lower pollution ($\bar{\bar{P}} < \bar{P}$) and capital ($\bar{\bar{K}} < \bar{K}$).*

If condition (3.16) holds, then in addition:

2. *Investment falls: $\frac{\partial K_{t+1}}{\partial s} > 0 \ \forall t \geq 0$ and*

3. *pollution falls: $\frac{\partial P_t}{\partial s} > 0 \ \forall t \geq 0$.*

As shown above, if subsidized firms are sufficiently more pollution intensive, the capital reallocation resulting from a decrease in the interest subsidy causes current pollution to fall. This is the capital resource reallocation effect described above. In addition, the reduction in interest subsidies lowers the overall return to capital, causing investment to fall. Since pollution is an increasing function of capital, future pollution and steady state pollution fall as well. This is the capital accumulation effect discussed above. Because the capital accumulation effect causes pollution to fall with subsidies regardless of pollution intensity, the steady state condition is weaker. That is, if (3.16) is not satisfied but $\sigma_G > \sigma_P$, then, following a decrease in interest subsidies, initially pollution rises but subsequently falls to a lower steady state.

It is straightforward to interpret the capital reallocation effect in terms of the familiar scale and technique effects. From equation (2.25):

$$\frac{\partial P}{\partial s} = \frac{\partial \sigma}{\partial s} Y + \sigma \frac{\partial Y}{\partial s}. \tag{3.17}$$

After simplifying, we obtain:

$$\frac{\partial P}{\partial s} = \left(\sigma_G - \sigma_P\right) \frac{\partial K_G}{\partial s} \frac{r\left(K\right)\left(\left(1-s\right) Y^P + Y^G\right)}{Y} - s\sigma \frac{\partial K_G}{\partial s} r\left(K\right). \tag{3.18}$$

Hence the technique term is positive for $\sigma_G > \sigma_P$ and the scale term is negative. Therefore, a decrease in the interest subsidy rate reduces current pollution through a technique effect and increases current pollution through a scale effect. Given condition (3.16), the technique effect dominates and a reduction in the subsidy rate causes pollution to fall. Reducing the interest subsidy lowers steady state output, since the increase in productivity is more than offset by the fall in steady state capital. Hence both the technique and scale effects cause steady state pollution to fall with subsidies, for $\sigma_G > \sigma_P$.

3.2 The Effect of Reducing Direct Subsidies

Next we consider a reduction in direct subsidies, holding the interest subsidy rate fixed. With s fixed, if subsidized firms are to earn zero profits direct subsidies can be reduced only by reducing the labor requirement. The following theorem shows that under a stronger condition, this experiment causes pollution to fall.

THEOREM 3 *Let F and u be as described above and suppose a decrease in l_G holding s*

fixed. Let $K_0 = \bar{K}$. Let:

$$\frac{\sigma_G}{\sigma_P} > \max\left\{\frac{w\left(K_t\right)}{A_G F_l\left(K_G\left(K_t\right), l_G\right)}, \frac{1}{1-s}\right\} \forall t \geq 0 \tag{3.19}$$

Then:

1. *pollution falls below $\bar{P}$ for all $t \geq 0$,*

2. *For periods $t > 1$, pollution transitions monotonically to a new steady state $\bar{\bar{P}} < \bar{P}$.*

In the current period we have a labor reallocation effect: when labor moves from subsidized to private firms, labor becomes more productive (from $A_G F_l$ to w), which tends to increase output and therefore pollution. However, since private firms are less pollution intensive, pollution tends to fall when labor moves from subsidized to private firms. Condition (3.19) requires the later of these two effects to be stronger. Capital also moves to the private sector, so we have a capital reallocation effect and require condition (3.16). The intuition for (3.19) is identical to the intuition for (3.16): both imply the reallocation of resources to the private sector causes a decrease in pollution intensity that outweighs the increase in output.

After the initial fall in pollution, the labor requirement is fixed, but a capital accumulation effect exists, as capital converges to a new steady state. If condition (2.6) does not hold, then capital declines monotonically to a new steady state and $\frac{1}{1-s}$ is larger than the wage ratio. Thus given condition (3.16) and not (2.6), pollution declines to a new steady state below the initial drop in pollution.

If condition (2.6) holds, then steady state capital may rise or fall after the reduction in the labor requirement and the wage ratio is larger than $\frac{1}{1-s}$. If steady state capital declines, pollution falls further. If capital rises then pollution rises, but not by enough to offset the initial fall in pollution. Figure (1) illustrates the time path of pollution.

For Cobb-Douglas production with labor share $1-\alpha$, the wage ratio in (3.19) is a function of only parameters:

$$\frac{w\left(K_t\right)}{A_G F_l\left(K_G\left(K_t\right), l_G\right)} = \left(\frac{A_P\left(1-s\right)^{\alpha}}{A_G}\right)^{\frac{1}{1-\alpha}}. \tag{3.20}$$

In the calibration, A_G turns out to be large enough so that $\frac{1}{1-s}$ is larger than the wage ratio and thus conditions (3.19) and (3.16) are identical.

We can also conclude that if condition (3.19) is satisfied, then a trade agreement which reduces both direct and interest subsidies (and therefore relaxes the labor requirement), also reduces pollution.

We can also break down the effect of direct subsidies into a positive technique term and a negative scale term. Thus condition (3.19) can be interpreted as a sufficient condition for the technique effect to dominate, so that a reduction in direct subsidies reduces current pollution.

3.3 The Effect of Reducing Tariffs

In the third experiment, we suppose a trade treaty requires the world to lower tariffs on the exported good. Equation (2.18) implies that this is equivalent to a shift of the world demand curve for the exported good, which increases Ω.

The effect of a trade treaty which lowers world tariffs on pollution is then:

THEOREM 4 *Let F and u be as described above and suppose an increase in Ω holding l_G and s fixed. Let $K_0 = \bar{K}$. Then:*

1. *There is no effect on current pollution,*
2. *investment rises,*
3. *pollution rises for $t \geq 1$,*
4. *The economy transitions to a new steady state $\left(\bar{\bar{K}}, \bar{\bar{P}}\right)$ with higher pollution ($\bar{\bar{P}} > \bar{P}$) and capital ($\bar{\bar{K}} > \bar{K}$).*

Note that given $\zeta\,(1 + \tau_D) < 1$ (satisfied if $\zeta = 0$), then an increase in domestic tariffs also increases Ω and pollution. If both foreign and domestic tariffs fall in a trade treaty, then the effect on Ω and therefore pollution depends on the size of the preexisting tariffs.

So a reduction of world trade barriers caused by the trade treaty means an increase in foreign demand, which in turn improves the return on capital and results in an increase in investment which in turn results in the creation of more pollution-causing factories.

No technique effect exists here, the only effect of a change in world tariffs is the effect on capital accumulation. In this sense, our results differ from the static model of Antweiler, Copeland, and Taylor (2001). We have assumed abatement policy is constant, and thus do not have their technique effect.

Hence a trade treaty that reduces subsidies as well as tariffs has an ambiguous effect on pollution. However, we argue here (and show in the simulations for the case of China) that overall pollution is likely to fall if (3.19) holds. The reason is that first both foreign and domestic tariffs generally fall, so the effect on Ω is ambiguous. But even if Ω rises, the trade treaty has an ambiguous scale effect on pollution causing-capital accumulation (interest subsidies fall but the return to capital increases with foreign demand), but an unambiguous technique effect on pollution, caused by capital flowing to the less pollution intensive private sector.

4 Computational Model

4.1 Extended Model

In this section we use a dynamic applied general equilibrium model in order to assess the quantitative effects of changes in tariffs and subsidies associated with China's accession to the WTO on pollution emissions. Our model is an extension of Bajona and Chu (2005) where we have added pollution emissions to the private and state sectors. In order to make quantitative predictions, the computational model adds several features not present in the theoretical model.[14] In particular, the computational model considers two final goods, a traded good and a non-traded good. Due to data availability, we assume that the pollution intensity of the private and the state sector do not vary across final goods. Some other extra features of the computational model include adjustment costs to investment and taxes on output. The model also features exogenous technological change in both TFP and pollution intensity. In what follows we present the equations and a brief overview of the model. See Bajona and Chu (2005) for the complete details.

[14]None of these features are critical for our qualitative analysis of the effect of subsidies to the state sector on pollution and, therefore, the intuition from the simplified model applies to the quantitative model.

The representative individual solves the following problem:

$$\begin{aligned}
\max \quad & \sum_{t=0}^{\infty} \beta^t \left(\epsilon c_{1t}^{\rho} + (1-\epsilon)\, c_{2t}^{\rho} - 1\right) \frac{1}{\rho} \\
\text{s.t.} \quad & p_{1t} c_{1t} + p_{2t} c_{2t} + a_{t+1} = w_t + (1 + r_t)\, a_t + TR_t \\
& a_t \geq -A \\
& a_t = q_{P1t-1} k_{P1t} + q_{P2t-1} k_{P2t} + q_{G1t-1} k_{G1t} + q_{G2t-1} k_{G2t} + \\
& k_{P10}, k_{P20}, k_{G10}, k_{G20} \text{ given}
\end{aligned} \tag{4.1}$$

where c_{1t} and c_{2t} are consumption of the traded and non-traded goods, respectively, p_{it} is the price of good i, and a_t represents the assets held by the individual. Consumers hold capital in each sector and industry, k_{ijt}. Here q_{ijt-1} is the return at period t of capital of type ij invested at $t-1$ to be used in period t. Adjustment costs make capital sector and industry dependent.

Production Y of sector i in industry j is:

$$Y_{ij} = \min \left\{ \frac{Z_{ij1}}{v_{j1}}, \frac{Z_{ij2}}{v_{j2}}, A_{ij} K_{ijt}^{\alpha_j} l_{ij}^{1-\alpha_j} \right\}, \ i = P, G \ j = 1, 2. \tag{4.2}$$

Here Z_{ijk} is the use of good k, v_{jk} is the quantity of good k needed to produce one unit of good j, $Y_{1j} + Y_{2j} = Y_j$, and A_{ij} is TFP, which grows exogenously at rate $(1+\gamma)^{1-\alpha_j} - 1$. The production function is thus Leontief relative to both the traded and non-traded goods, and Cobb-Douglas with respect to the capital and labor inputs. This choice of production function, standard in the literature of applied general equilibrium models, simplifies the calibration of the parameters from the input-output tables.

The Armington aggregator in the tradeable sector is CES:

$$Y_{C1} = E \left(\mu X_D^{\zeta} + (1-\mu)\, M^{\zeta} \right)^{\frac{1}{\zeta}}. \tag{4.3}$$

Here $\frac{1}{1-\zeta}$ is the elasticity of substitution between the domestic and foreign produced traded goods, E is a technology parameter, and $Y_{C2} = Y_2$.

Investment goods, I, are produced using the traded and non-traded goods as inputs:

$$I = A_I Z_{I1}^{\nu} Z_{I2}^{1-\nu}. \tag{4.4}$$

Here, Z_{Ij} represents the quantity of good j used as an intermediate input in the investment sector. The investment good can be used in either sector to increase the sector's capital stock. Since the change in pollution is sensitive to changes in capital stock across sectors and over time, it is important to have a realistic model of capital adjustment. Therefore, following Lucas and Prescott (1971), we model sectoral and temporal adjustment costs as:

$$K'_{ij} = \mathrm{AC}\left(\frac{I_{ij}}{K_{ij}}\right) K_{ij} + (1-\delta) K_{ij}. \tag{4.5}$$

Here AC is the adjustment function which satisfies:

$$\mathrm{AC}\left(\frac{I}{K}\right) \equiv \left((\gamma - 1 + \delta)^{1-\theta}\left(\frac{I}{K}\right)^{\theta} - (1-\theta)(\gamma - 1 + \delta)\right)\frac{1}{\theta}, \quad 0 < \theta \leq 1. \tag{4.6}$$

The government obtains revenue from taxes on producers of final goods, T, and from tariff revenue, TF. The tax rates t_i and the tariff rate τ_D are exogenously given. The government purchases per capita, G_j, are also exogenous. The government budget constraint is thus:

$$p_1 G_1 + p_2 G_2 + s \sum_j r K_{Gj} + S + TR = TF + T. \tag{4.7}$$

Here tax revenues are:

$$T = \sum_{i,j} p_j t_i Y_{ij}, \tag{4.8}$$

and tariff revenues are as in Section 2.3.

For trade, foreign demand is again given by (2.17), where $\hat{D}$ now grows exogenously at rate γ, which is consistent with the existence of a balanced growth path for the model economy. Note that we are assuming foreign and domestic households have the same elasticity of substitution between foreign and domestic goods.

All markets clear, so trade balances (2.19 holds) and domestic and foreign demand for the traded good must equal supply (2.22) holds for good 1. The domestic markets for the non-traded good and the composite good also clear:

$$G_j + C_j + Z_{Ij} + \sum_{i,j} Z_{ijk} = Y_{Cj}. \tag{4.9}$$

Exogenous improvements in emissions intensity, $\frac{1}{EI}$, slow the growth of pollution emissions:

$$P = \sum_i \sigma_i \frac{Y_{1i}}{EI} \tag{4.10}$$

Here EI grows exogenously at rate γ, which is consistent with a stationary level of pollution emissions.

4.2 Data and Calibration

Calibration of the economic parameters is identical to Bajona and Chu (2005) to which we refer for explicit details. The economic parameters of the model are calibrated in order to match data on the Chinese National Income and Product Accounts, the Chinese input-output matrix, and the share of SOEs in Chinese industry for 1997. The values of the calibrated parameters are reported in Table 1.

Specific to this paper is the calibration of the pollution intensity parameters. We use the results of Wang and Jin (2002), who conducted a survey of pollution emissions of 905 industrial firms in China in 1999. They report the average pollution intensity of output, σ, for four flow pollutants: total suspended solids (TSS), chemical oxygen demand (COD), sulfur dioxide (SO_2), and total suspended particles (TSP). Wang and Jin (2002) report pollution emissions by type of ownership: SOEs, collective owned enterprises (COEs), Private, foreign, and joint ventures. We categorize SOEs as subsidized firms and all other types of ownership as private.[15] The pollution intensity of private firms equals the total pollution emissions divided by the total output of the four sectors. The parameters are reported in Table 2.

[15] Ideally, firms should be categorized according to whether or not they receive subsidies. This data is not available. However, we view our assumption that only SOEs get subsidies as conservative. For example, COEs are more pollution intensive than private firms, and probably receive some subsidies. Finally, we do not want to use studies which compare intensity of SOEs before and after privatization, as the subsidies are likely to be (at least in the short run) similar.

Unfortunately, the survey was done in 1999, so our assumption is that pollution intensity did not significantly change between 1997 and 1999.

	Emissions in Tons per 10,000 Yuan			
Firm Type	TSS	COD	SO_2	TSP
SOEs (σ_G)	2.5	21.4	3.2	0.2
Private and Other (σ_P)	2.00	7.29	0.08	0.02
$\sigma_G(1-s)-\sigma_P$	-0.95	1.70	1.26	0.06

Table 2: Pollution intensity of SOEs and other enterprises. Derived from Table 4 of Wang and Jin (2002). The last line uses $s = 0.58$, the capital-weighted average of the traded and non-traded sectors.

5 Simulation Results

The numerical experiment is to quantitatively assess the effects on pollution emissions derived from changes in subsidies to SOEs required for China's accession to the WTO. The initial year for each simulation is 1997. China has been reforming its economy at least since the early 1980s, to improve economic performance and comply with trade rules and agreements. Since it is not clear which subsidies are reduced for what reason, we focus instead on subsidies specifically targeted for elimination in the US-China WTO Bilateral Agreement (White House 1999). The agreement, signed in 1999, gives a timetable for elimination of subsidies of 0 to 15 years, depending on the good. We chose a five year reform period (2000-04) since most goods have a five year timetable.

Although the policy changes are not fully implemented until 2004, households change decisions beginning in 1997, in anticipation of the new policies. Changes in investment in these early years is especially complicated. For example, suppose households know the interest subsidy rate and therefore the future return to capital are to fall. Because of adjustment costs, capital created from current investment cannot be costlessly transformed into consumption when the policy takes effect. Therefore, the return to current investment falls. However, the incentive to reduce current investment is mitigated by households desire for smooth consumption. Since households know future wealth and consumption will fall, an incentive to reduce current consumption and increase current investment exists. Since pollution is proportional to output, pollution also changes in anticipation of the new policy in complicated ways. Our results therefore give caution to static empirical work in this area, since pollution is likely to vary significantly along the dynamic path to the new balanced growth path.

We consider five policy experiments. The first, which we denote the benchmark economy, assumes the WTO agreement is not signed and future policies remain at their 1997 values. In the other four experiments, policies change over the five year reform period. The benchmark economy is not in a steady state in 1997. Therefore, to isolate the effects of the changes in subsidies, we present all results relative to the benchmark economy.

In the second experiment, the labor requirement is reduced by 25% so that direct subsides fall by 25%. This experiment is most conservative in the assessment of the changes required for China to enter the WTO, as it supposes only subsidies China specifically agreed to eliminate in the WTO agreement will in fact be eliminated. Of the subsidies specifically marked for elimination in the WTO agreement, most are direct subsidies. Bajona and Chu (2005) estimate elimination of these subsidies constitutes a 25% reduction in direct subsidies. Although interest subsidies are not specifically marked for elimination, they are not allowed and could be eliminated if another country brought suit, or if (as promised) China opens its banking sector. The implied reduction in the labor requirement moves labor to the private sector. The movement of labor to the private sector increases the marginal product of capital, so capital also moves to the private sector. Both of these effects raise output, eventually to 2.36% above the benchmark model. Since pollution is proportional to output, this scale effect causes pollution to rise. However, the private sector is less pollution intensive, so the movement of labor and capital to the private sector results in a technique effect which causes pollution to fall. As shown in Figures 2-5, pollution falls relative to the benchmark for three of four pollutants, from a small increase in TSS of 0.5% to a 22.9% decrease in SO_2. This matches the results from the theory as shown the last line of Table 2. Thus pollution generally falls in our most conservative experiment in which no reduction in interest subsidies exists, and for which COEs are treated as private firms.

The second experiment is an exercise which shows the effect of a 10% reduction in the interest subsidy rate, holding the labor requirement fixed. The reduction in the subsidy rate lowers the overall return to capital and causes existing capital to flow to the private sector. The resulting fall in investment lowers steady state output relative to the benchmark economy. The steady state scale effect therefore reduces pollution here. Production also moves to the less pollution intensive private sector, further reducing pollution. Thus the scale effect and technique effect both result in a decrease in steady state pollution. As shown in Figures 2-5, steady state emissions of all four pollutants fall relative to the benchmark, from a 0.9% fall in TSS to 27.0% fall in SO_2.

The third experiment is a comparative static which shows the effect of a 10% reduction in the interest subsidy rate, holding direct subsidies fixed so that the labor requirement falls by 13%. The fall in pollution is more moderate; output rises by only 0.01% since the lower investment is offset by labor moving to the higher TFP private sector. Nonetheless, pollution declines relative to the benchmark in all four cases.

The final experiment supposes the world reduces tariffs to zero. This causes an increase in demand for Chinese goods and a corresponding increase in output. As shown in Figures 2-5, pollution rises, since in this case there is no technique effect. Relative to the benchmark, TSS increase by 0.45%, COD by 0.46%, SO_2 by 0.49%, and TSP by 0.48%. The effect of changes in tariffs on pollution is apparently quantitatively small relative to the effect of changes in subsidies. Tariffs are small to begin with, so even eliminating tariffs does not cause large changes. In contrast, our calibration indicates that SOEs receive a 58% discount on their capital rental, so a 10% reduction in these subsidies has quantitatively large effects. Secondly, since there is a relatively large difference in productivity between the state owned and private sectors, moving inputs from one sector to the other has a quantitatively large effect on output and interest rates relative to the effect of a change foreign demand.

Figure 6 breaks down the change in pollution into scale and technique effects for all pollutants and all experiments. As noted earlier, the technique effect is stronger where the difference in pollution intensity is greatest, for TSP. The scale effect is positive for the reduction in direct subsidies and the reduction in world tariffs. Notice the scale effect, in percentage terms, is independent of the pollutant.

6 Conclusions

We have given theoretical sufficient conditions for which a reduction in subsidies required by a trade agreement results in a decrease in pollution. Essentially, these conditions require the subsidized sector to be sufficiently more pollution intensive than the private sector. We argue SOEs or other firms receiving various government subsidies are likely to also receive another kind of subsidy: lax enforcement of pollution regulations. Indeed, for the case of China, SOEs are more pollution intensive for all four pollutants studied. Hence in our numerical section, we show that, under the most conservative assumptions, upon entry in the WTO pollution falls for three of four pollutants. We also show that that changes in tariffs have a minimal effect on pollution relative to changes in subsidies.

Several caveats are in order. First, given that China's state owned sector comprises about 30% of industrial output, China represents an extreme case. Still, given the evidence weak enforcement of environmental regulations on SOEs in India and Argentina, and the prevalence of SOEs in developing countries, our model is likely very relevant for developing countries. Further, given that nearly all countries give some subsidies, our model will have at least some relevance in developed economies as well. Second, subsidized firms here are competitive. Subsidized firms may have monopoly powers. If the subsidized firm is state owned, it may suffer from agency issues. Each of these firm structures may affect pollution. Finally, our model has only one traded good and may thus miss intra-sectoral effects of lowering tariffs.[16]

Exogenous subsidies here are the outcome of the political process. Modeling this process is a subject of future research. Regardless of the political process, a free trade agreement, by creating new winners and losers, has the possibility of altering the political equilibrium. The trade agreement thus can potentially reduce pollution-causing subsidies in a way that a privatization may not. If the political equilibrium is unchanged, privatization is unlikely to produce significant changes.

In effect we have found a new channel for which economic policy affects pollution, a tech-

[16]For example if a particular good was pollution intensive and had high world tariffs, then the effect of tariff reductions on pollution may be more significant than what we obtain here.

nique effect that results when production moves from a more pollution intensive subsidized firm to a less pollution intensive private firm. This technique effect could be examined in many other contexts. For example, countries with low subsides are both richer and have a cleaner environment, thus our model would likely reproduce the environmental Kuznets curve. Our model could also be used to examine the effects of privatization on pollution. These are subjects of future research.

7 Appendix: Proof of theorems

7.1 Proof of Theorem 1

Substituting the interest rate (2.4), wage rate (2.5), and transfer (2.21) into the budget constraint for the aggregate good (3.6) and simplifying results in:

$$c + k' = G(k, K; s) \tag{7.1}$$

$$G(k, K; s) \equiv \Omega \left[Y(K; s) + A_P F_k (K - K_G(K; s), 1 - l_G)(k - K) \right]^{\phi} + (1 - \delta) k \tag{7.2}$$

$$Y(K; s) \equiv A_P F(K - K_G(K; s), 1 - l_G) + A_G F(K_G(K; s), l_G) \tag{7.3}$$

The model is now in the framework of Greenwood and Huffman (1995). By repeatedly appealing to (2.10), and the properties of the interest rate (2.8) and the share of capital in the subsidized sector (2.7), we can verify assumptions (i)-(iii) of Greenwood and Huffman. It follow from their proposition on page 615 that an equilibrium exists.

Further, equation (3) of Greenwood and Huffman states that the equilibrium investment function H is the fixed point a recursive non-linear functional equation. The fixed point of this equation is the Euler equation. Hence H satisfies the Euler equation.

Equation (4) of Greenwood and Huffman states that H has the following properties:

$$0 \leq H_K(K) \leq G_1(K, K) + G_2(K, K) \tag{7.4}$$

$$0 < H(K) < G(K,K) \tag{7.5}$$

Equation (7.4) implies that $c(K)$ is increasing in K. Thus since u is concave, for all K, K':

$$\left(u_c(c(K)) - u_c(c(K'))\right)(K - K') \leq 0. \tag{7.6}$$

Substituting in the Euler equation, we see that $K' > K$ if and only if $K < \bar{K}$. Thus H is concave. Thus H has the properties stated in Theorem 1.

7.2 Proof of Theorem 2

As shown in the text, condition (3.16) implies a decrease in the subsidy decreases pollution.

For the steady state, let $\beta = \frac{1}{1+\lambda}$, where λ is the rate of time preference. Evaluating equations (3.10) and (3.11) at the steady state $\bar{K}$ yields the modified golden rule:

$$\lambda = \phi \Omega Y\left(\bar{K}; s\right)^{\phi-1} r\left(\bar{K}; s\right) - \delta \tag{7.7}$$

Now since steady state income, $Y\left(\bar{K}; s\right)$ is decreasing in the subsidy, $\phi < 1$, and $r\left(\bar{K}; s\right)$ is increasing in the subsidy, the right hand side is increasing in the subsidy. Further, since $Y\left(\bar{K}; s\right)$ is increasing in $\bar{K}$, $\phi < 1$, and $r\left(\bar{K}; s\right)$ is decreasing in $\bar{K}$, the right hand side is decreasing in $\bar{K}$. Hence a decrease in the subsidy implies a decrease in $\bar{K}$. It is straightforward, but tedious, to verify that $\bar{P}$ is increasing in s given $\sigma_G > \sigma_P$, using (7.7).

For periods between 0 and the steady state, note that from Theorem 1, $H(K)$ is strictly increasing and concave in K. Hence, K will converge monotonically to $\bar{\bar{K}}$ from above, since $K_0 > \bar{\bar{K}}$. Given that pollution is increasing in the capital stock, pollution will also converge monotonically from above to $\bar{\bar{P}}$.

7.3 Proof of Theorem 3

Differentiating pollution with respect to l_G, holding K fixed, we see that current pollution falls given condition (3.19). In addition, differentiating the steady state pollution with respect to l_G implies that steady state pollution falls given in addition condition (2.6). Let

$P_0 < \bar{P}$ denote the new pollution emissions in the initial period.

For periods between 0 and the steady state, if capital is increasing, then pollution will increase monotonically to the new steady state $P_0 < \bar{\bar{P}} < \bar{P}$. If capital is decreasing, then pollution will decline to the new steady state $\bar{\bar{P}} < P_0$. The reasoning is identical to Theorem 2.

7.4 Proof of Theorem 4

Current pollution is a function of only the current capital stock, tax rates, and l_G, all of which are given. Hence current pollution is independent of Ω. For the steady state, note that modified golden rule (7.7) for this economy implies that if Ω rises then so does steady state capital. Since steady state pollution is increasing in the steady state capital stock for $\sigma_G > \sigma_P$, steady state pollution rises.

For periods between 0 and the steady state, capital and pollution will increase monotonically to the new steady state, using identical reasoning as in Theorem 2.

8 Appendix: Tables and Figures

Parameter	Symbol	Value		Matches:
Production Parameters		Traded	Non-Traded	
Capital Share	α	0.24	0.38	(a)
Productivity, Private Sector	$A_{Pj,0}$	5.29	2.97	(a)
Productivity, SOEs	$A_{Gj,0}$	2.45	2.65	(a)
Unit Cost, traded	v_{1j}	0.54	0.11	Input-Output Tables (I/O)
Unit Cost, not-traded	v_{1j}	0.37	0.19	I/O
Growth rate, GDP	γ		0.02	US Trend
Armington Aggregator				
Technology Parameter	E		1.67	Equilibrium
Elasticity Parameter	ζ		0.5	AGE Literature
Share Parameter	μ		0.72	I/O, Equilibrium
Investment Parameters				
Capital Share	ν		0.38	I/O
Productivity	A_I		1.94	Equilibrium
Depreciation	δ		0.08	Investment Data
Adjustment Costs Parameter	θ		0.9	US I/K Volatility
Preference Parameters				
Discount Rate	β		0.95	One year period
Elasticity Parameter	ρ		-1.00	within RBC range
Share of traded good	ϵ		0.87	I/O
Foreign Demand	$\hat{D}_0$		0.44	I/O
Policy Parameters		Traded	Non-Traded	
Production Tax	t	0.12	0.08	(a)
Government Consumption	G_j	0.00	0.21	I/O
Rental rate subsidy	s	0.82	0.15	(a)
Labor Restriction	l_{Gj}	0.19	0.18	(a)
Domestic Tariff	τ_D		0.02	Tiwari, et. al. (2002)
Foreign Tariff	τ_F		0.05	Tiwari, et. al. (2002)
Initial Values		Traded	Non-Traded	
Initial Private Capital	K_{Pi0}	0.65	0.52	K series
Initial Government Capital	K_{Gi0}	0.96	0.56	K series
Foreign Borrowing	B_0		0.00	I/O, K series

Table 1: Economic parameter values. (a): jointly calibrated to match output and labor inputs from input-output tables (I/O), the constructed capital stock by ownership in 1997, the share of output in each industry produced by SOEs in 1997, share of output in the traded industry produced by SOEs in 1997, the direct subsidies to GDP ratio for 1997, and the assumption of equal capital shares in the private and state sectors. Here j indexes the type of good (traded and non-traded). These parameter values are identical to Bajona and Chu (2005), Table 1.

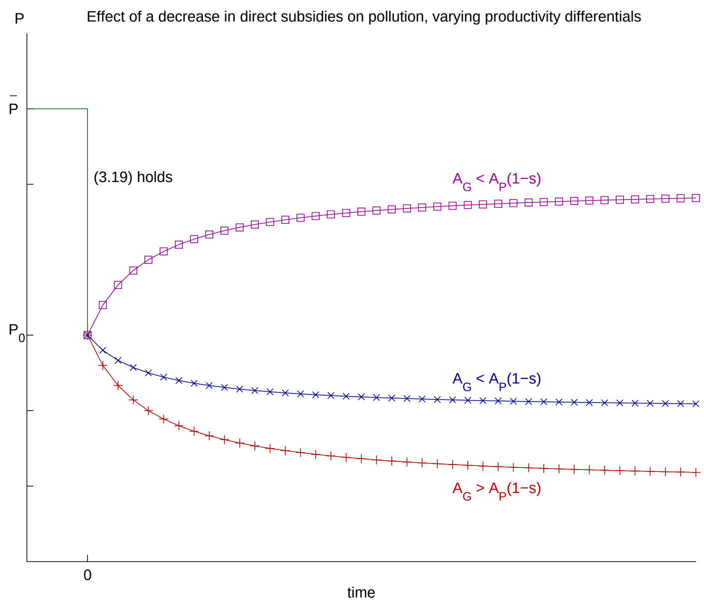

Figure 1: Changes in pollution resulting from a decrease in direct subsidies over time as a function of SOE productivity, given condition (3.19) holds.

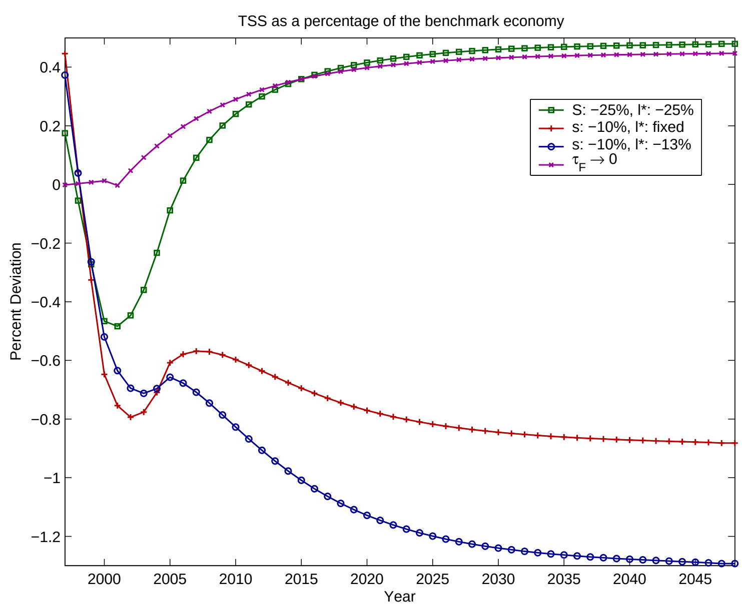

Figure 2: Total Suspended Solids relative to benchmark economy with no changes in tariffs and subsidies. Changes in tariffs and subsidies are phased in over years 2000-2004.

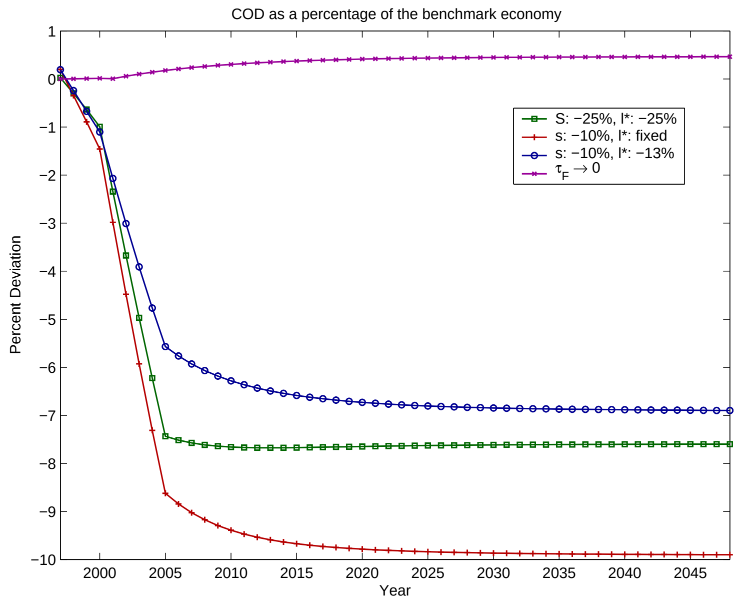

Figure 3: Chemical oxygen demand relative to benchmark economy with no changes in tariffs and subsidies. Changes in tariffs and subsidies are phased in over years 2000-2004.

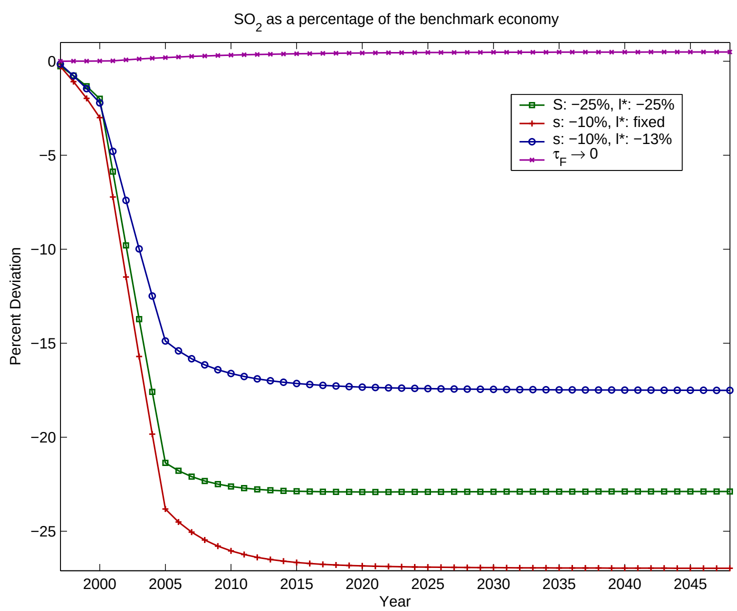

Figure 4: Sulfur Dioxide Emissions relative to benchmark economy with no changes in tariffs and subsidies. Changes in tariffs and subsidies are phased in over years 2000-2004.

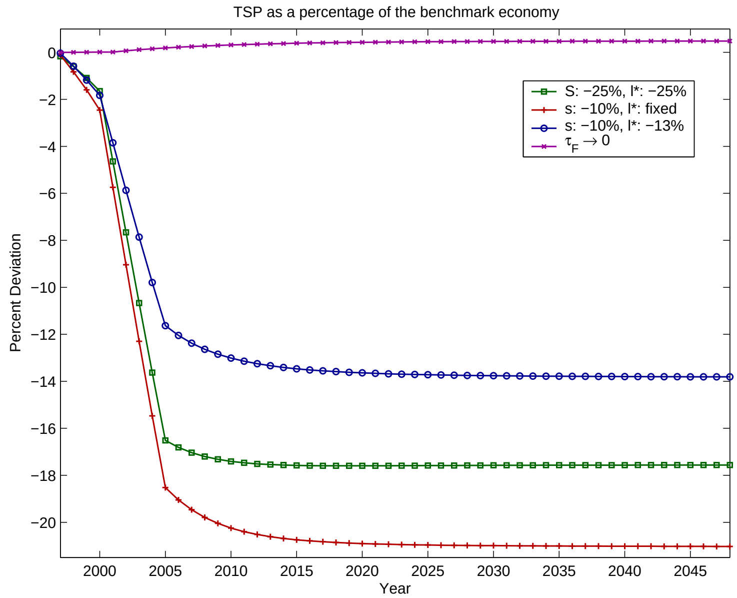

Figure 5: Total suspended particulates relative to benchmark economy with no changes in tariffs and subsidies. Changes in tariffs and subsidies are phased in over years 2000-2004.

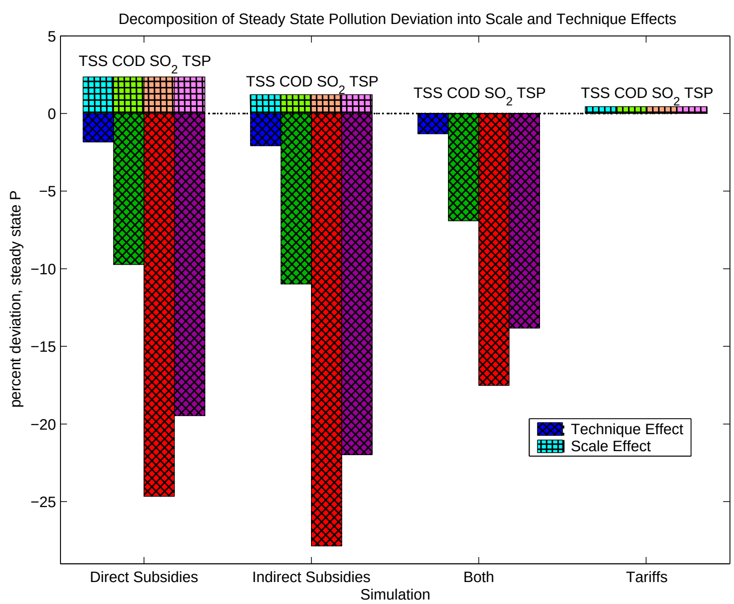

Figure 6: Decomposition of steady state change in pollution relative to the benchmark economy into scale and technique effects.

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