# Fiscal Instruments for Pollution Control: Attractions, Limitations, and Strategies

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Fiscal instruments are an important item in the policy maker's toolkit for promoting efficient energy use and protecting environmental quality. These policy instruments can help bring the prices of goods and services closer to their full social cost – the private cost plus the external environmental cost. This encourages cleaner production and consumption decisions and can help societies achieve a better balance between environmental quality and other valued goods and services such as affordable transportation, food, housing, and energy.

China already makes use of these instruments -- for example, through its pollution levy system. However, exploring possible additional or modified uses of these instruments can reveal ways that the nation can protect its environment at low cost as it continues its rapid rate of economic growth.

There is a wide range of potential fiscal approaches to environmental protection and efficient energy use. These include:[1]

**Taxes** on emissions or effluent releases (as under the pollution levy), or on goods and services associated with pollution (as with a gasoline tax)

**Tax Credits** for clean consumer activities (for example, purchasing an energy-efficient refrigerator), or for clean production activities (for example, producing electricity from renewable sources)

**Subsidies** to research and development toward the invention of new, clean technologies

**Policy packages:** One example is green tax reform -- a combination of an environmental levy and a reduction in ordinary income or sales taxes, where the income or sales tax cut is financed by revenues from the environmental tax. Another example is an environmental tax-subsidy package --- for example, using environmental taxes to finance either subsidies to R&D or tax credits for clean producer or consumer activities.

In this brief paper I address the following questions related to the use of these various fiscal instruments:

1. What are the potential attractions and limitations of fiscal instruments?

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[1] Another important and promising policy approach is tradable pollution allowances. I do not focus on this approach because it usually is not considered in the category of "fiscal instruments." In another paper (Goulder, 2005) I consider the relative attractions and deficiencies of pollution levies and tradable allowances for China.

2 Which types of fiscal instruments are best?

3. Do fiscal instruments make conventional regulation (direct controls) unnecessary?

4. How extensively are fiscal instruments used in various countries?

5. Is it worthwhile for China to expand the use of these instruments now? Or does the "Environmental Kuznets Curve" imply is better to wait until a higher per-capita income level is attained?

## 1. What are the potential attractions and limitations of fiscal instruments?

In most industrialized nations, direct regulation – including energy efficiency standards, emissions quotas, and mandated technologies – is the most commonly used approach for promoting energy efficiency or controlling pollution. However, incentive-based, fiscal approaches are gaining in importance.

### a. Attractions

Economists have often touted the attractions of fiscal approaches[2]. Some potential attractions include:

- Cost-effectiveness. Fiscal approaches have the potential to achieve given targets for reduced pollution or reduced energy use (energy per unit of service) at lower cost than direct regulation. To achieve pollution-reduction at the lowest cost, the marginal costs of pollution-reduction should be the same across all facilities that reduce pollution. Fiscal approaches like pollution levies or tax-breaks for pollution reductions can accomplish this, even without the regulator knowing what each facility's costs are. This is because such instruments give facilities an incentive to reduce pollution up to the point where the marginal abatement cost equals the tax benefit (the tax-payment avoided or tax-credit earned as a result of the marginal reduction in pollution). In contrast, under direct regulation the regulating authority would need to know the abatement costs of each facility to determine the pollution-reductions of each facility that would achieve an aggregate reduction at the lowest cost. Thus, a potential advantage of fiscal approaches is that they can help assure that pollution-reductions are accomplished where they can be made most cheaply.

- Innovation incentives. Taxes on emissions or tax-breaks for emissions reductions provide a continual stimulus toward technological innovation. This is the case because inventing a cleaner production method is a way of avoiding taxes or receiving a larger tax break. In contrast, under direct regulation, there often is no further incentive to

[2] For a review of potential attractions and deficiencies of fiscal approaches and other incentive-based approaches, see, for example, Stavins (2005).

innovate once the required equipment is installed or once the emissions fall within the maximum allowable amount.

- Efficient source of public revenue. Taxes on emissions allow for socially beneficial "green tax reform." Such reform substitutes taxes on "bads" like pollution for taxes on "goods" like work or investment. The revenue from pollution levies or taxes on polluting fuels can be used to finance reductions in income taxes or sales taxes. This confers economic benefits, because lower rates of income or sales taxes imply lower distortions by the tax system. It may also confer political benefits, since there may be broad support for lower income or sales taxes.

**b. Drawbacks**

Larger share of overall social burden often falls on polluting facilities. Policies differ in terms of the share of the total economic burden that is placed on the polluting facilities. Compared with direct controls, emissions taxes, fuel taxes, and other environmentally motivated taxes tend to place a larger share of society's total policy cost on the polluting facilities. Direct regulation such as efficiency standards and facility-level emissions caps place a smaller share of this total cost on such facilities. In nations where polluting facilities constitute a concentrated and highly mobilized political group – and this is the case in the U.S. – there may be stronger political opposition to emissions taxes and fuel taxes than to direct regulation.

However, emissions taxes and fuels taxes can be designed in such a way as to avoid putting a large share of the burden on polluting facilities. This can be accomplished by exempting "inframarginal" emissions or use of fuels from the tax.[3] Under this approach, facilities still pay the emissions tax or fuel tax "at the margin" – that is, for the last units of emissions or fuel input – but they do not need to pay tax for the first units. Economic analysis shows that this leads to the same reductions in pollution or fuel use as the simpler tax without exemptions – yet it reduces substantially the burden on the regulated facilities. In fact, this approach can entirely eliminate the loss in profit or income to polluting facilities. This can significantly reduce public opposition.

Greater visibility of the burden from regulation. The costs of regulation may be more visible under these fiscal instruments than under direct controls. Under pollution taxes, producers or consumers can be very aware of the tax-component in the price of a fuel input, produced good, or service. In contrast, under direct regulation, the higher costs necessitated by the regulation may be less obvious. For example, purchasers of automobiles may not have a good sense of the degree to which required pollution-control equipment leads to a higher price of the automobile. The greater visibility of regulatory cost in the case of pollution or fuel taxes may lead to greater public opposition to these approaches.

Quantity of emissions is left uncertain. Under fiscal approaches, regulators can predict to some degree what facilities' pollution-reduction costs will be at the margin: this will be tax

[3] For an analysis of this issue, see Bovenberg and Goulder (2001) and Goulder (2000).

rate. However, regulators generally will not be able to predict in advance the extent of pollution-reduction that will occur. This depends on every firm's technological alternatives, and on the costs of each of these alternatives. Regulators do not have all of this information. Thus, under the emissions tax, regulators can predict marginal pollution-reduction costs but will be uncertain as to the amount of emissions reductions that the tax will induce, or the remaining amount of emissions. In contrast, under emissions quotas or systems of tradable emissions allowances, the regulator specifies the aggregate amount of emissions. The ability to reduce uncertainty about total emissions was apparently a important factor leading to the implementation of national emissions targets (rather than setting prices for greenhouse gas emissions) under the Kyoto Protocol.

Thus, while fiscal approaches have many advantages relative to direct regulation, they face some disadvantages as well. Yet some of the disadvantages can be eliminated through careful policy design – especially the problem of excessive impacts on the profits of polluting firms.

## 2. Which types of fiscal instruments are best?

The beginning of this paper identified a range of fiscal approaches to energy efficiency and environmental protection: taxes on pollution or pollution-related fuels, tax credits for clean production or consumption, subsidies to R&D, and policy packages.

Note that two of these general approaches – tax credits and R&D subsidies – can be viewed as "carrots" in that they reward facilities for reducing pollution or for efforts to invent new technologies for doing so. They offer a payment to the facilities. In contrast, the first approach – taxes on pollution or fuels – can be regarded as a "stick" because it penalizes facilities for producing pollution. From the point of view of social cost, which approach is best? Is it best to focus on carrots, on sticks, or on a combination of the two?

From a political perspective, it may be attractive to employ only the carrots. Tax-breaks for cleaner energy use (carrots) are a major component of the recent Energy Policy Act the U.S., as well as the Bush Administration's proposed climate-change action plan. In contrast, there is virtually no use of taxes on inefficient or pollution-intensive uses of energy.[4]

However, from an economic perspective, concentrating solely on carrots can be very wasteful. The reason is that private markets can fail in two ways, and that a combination of instruments is generally necessary to address both "market failures" most effectively.

<u>The pollution market failure</u>. Emissions taxes focus most effectively on a "pollution market failure" -- the problem of environmental externalities. The pollution generated from industrial activities is a cost to society that (absent regulation) is not borne by the polluting facility. In effect, the private cost of production (including the cost of labor, materials, and other inputs) falls short of the full social cost, which includes the environmental cost. For example, the production of electricity from coal generates a range of pollutants, including NOx

[4] Tierney (2005) provides further discussion of this issue.

compounds, sulfur dioxide, and carbon dioxide. In the absence of regulation, the health and other damages from these pollutants are not included in the price of electricity, and thus the price of electricity does not incorporate the full social cost. Under these circumstances markets fail to allocate resources efficiently – there is too much pollution in the sense that the cost of reducing pollution would be less than the benefits in the form of avoided damages from pollution. Emissions taxes can address this problem by bringing the price of electricity in line with the full social cost. Economic analysis indicates that the environmental benefits from such taxes will exceed the costs to facilities and society in general associated with the higher prices.

The innovation market failure. A second market failure relates to innovation effort. Research and development activities, if productive, generate new knowledge. In general not all of this new knowledge can be appropriated by the individuals that undertake efforts to develop the new knowledge: some knowledge "spills over" to others, often competing enterprises. Thus, not all of the social return from investments in research and development efforts is enjoyed by the firm conducting those efforts. To put the matter another way: research and development efforts often produce a beneficial externality in the form of new knowledge enjoyed by outside parties. Economic analysis indicates that under these circumstances, the level of R&D undertaken by private firms will be insufficient from an efficiency point of view: that is, a larger amount of R&D would in general create additional social benefits (from the new knowledge) that exceed the extra cost. Under these circumstances technology-push policies – government provided research or subsidies to private research -- have an efficiency justification.[5]

Thus two market failures justify both a carrot (the R&D subsidy) and a stick (a tax on pollution externalities). The issue is not merely of academic interest. If only one of the two approaches is adopted, the costs of achieving given pollution-control targets can be significantly higher. In this connection, Goulder and Schneider (1999) find that the costs of reducing cumulative U.S. carbon dioxide emissions by 15 percent from 1995-2095 are an order of magnitude lower when both types of policy are employed, compared with the case where only a technology-push policy is used. Fischer and Newell (2005) obtain roughly similar results.

## 3. Do fiscal instruments make conventional regulation unnecessary?

Emissions taxes and other fiscal instruments can remove the need for some direct controls. This is particularly the case if the instruments are introduced upstream, that is, at the point involving primary inputs like fossil fuels. For example, a carbon tax, if imposed on suppliers of primary fuels, would encourage electric power generators to switch to cleaner fuels sources such as hydroelectric power, wind power, or geothermal energy. Or it could encourage the generators to switch from coal (which is relatively highly taxed per unit of energy) to natural gas (which would be relatively lightly taxed). Thus, under an (upstream) carbon tax, there is no need for direct fuel-switching requirements.

[5] Harvey (2005) offers a discussion of innovation market failures, R&D expenditure, and learning-by-doing in the context of climate-change policy.

However, several types of economic activity are not easily addressed through fiscal instruments. Emissions from mobile sources such as cars and planes are difficult to monitor. Similarly, non-point sources of water pollution are virtually impossible to identify. In these cases, direct controls such as efficiency standards or mandated technologies can have an advantage over fiscal instruments. It may be easier and less costly to monitor whether a given facility has installed a "clean" type of production equipment than to monitor emissions.

Thus, while fiscal instruments remove the need for some direct controls, they do not eliminate it. A system involving both types of regulation is likely to be most effective in promoting energy efficiency and a clean environment. However, it does appear that in many countries – China included – social welfare could be enhanced through expanded use of fiscal instruments. I address this issue in Section 5 below.

## 4. How extensively are fiscal instruments in various countries?

These instruments are used very broadly in the more industrialized countries, and their use is significant and growing in developing countries. There is considerable variety across nations in the types of fiscal instruments used, and in the magnitudes of the relevant tax or subsidy rates.

Table 1 gives an idea of the extent of use of one type of fiscal instrument: environment-related taxes. It shows that in 1997 the OECD countries relied on environment-related taxes for about five and a half percent of its overall tax revenue. The U.S. relied on such taxes for about 3.4 percent of its tax revenue. In the listed countries the environment-related taxes included (1) taxes on emissions of various air and water pollutants; (2) taxes on oil, coal, natural gas, and refined fuels (e.g., gasoline and diesel fuel); (3) taxes on hazardous or toxic wastes, (4) and various taxes on goods associated with pollution (nitrogen fertilizers, motor vehicles, etc.).[6]

Of course, the fact that these instruments are used broadly does not necessarily imply they are used well. On the positive side, numerous studies indicate that administrative costs for emissions taxes and fuels taxes are considerably lower than the costs would be for comparable direct controls.[7] On the negative side, in many nations (and probably in most), the tax rates on pollution and polluting fuels are well below the marginal damages from pollution – the rate that according to economic analysis would maximize the net benefits from pollution-control. In fact, many nations employ negative rates – that is, they subsidize pollution-related goods or services. The World Bank's 1992 *World Development Report* examined fossil fuel, electricity and water prices in 22 developing countries and the United Kingdom. In all but two cases

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[6] Stavins (2003) offers a detailed survey of the incentive-based instruments used in various countries for environmental protection. Incentive-based instruments include the fiscal policies mentioned in this paper, as well as tradable pollution allowances and deposit-refund systems.

[7] See, for example, Tietenberg (2004).

(electricity pricing by Turkey and the Philippines), subsidies caused prices to fall below cost, even before accounting for environmental externalities.

Below we discuss the tax-rate issue as it relates to China.

## 5. Is it worthwhile for China to expand use of these instruments *now*? Or does the "Environmental Kuznets Curve" imply it is better to wait until a higher per-capita income level is reached?

Using data from many countries, a number of studies have found evidence of an "Environmental Kuznets Curve" (EKC). The curve relates per-capita income to environmental quality[8], and indicates that environmental quality initially falls (or pollution rises) as per-capita increases, but environmental quality starts to improve (or pollution decreases) once per-capita income exceeds a certain threshold value. Although the estimates vary greatly, a typical threshold value is 7000-9000 U.S. dollars, or about 30,000-39,000 RMB (using exchange rates based on purchasing-power parity).[9]

Does this imply it's best for China to wait until per-capita income reaches this level before aggressively addressing energy efficiency and pollution?

### a. Theory

Typical behavior is not necessarily optimal behavior. Although the EKC may indicate a typical pattern, it does not reveal what is best for a nation. Even if national environmental quality tends to begin to improve once per-capita income reaches about 7-9 thousand U.S. dollars, theoretical and empirical studies indicate that significant environmental governance should take place even at lower per-capita income. Such analysis indicates that the social benefits from earlier action (in the form of avoided environmental damages) will exceed the costs of the environmental regulation. At least two main arguments apply:

a. Without current public promotion, <u>invention and market-penetration of new, clean technologies will occur later than what is best for society</u>. Underlying this result are the two "market failures" mentioned in Section 2 above.

> The *innovation market failure* reflects the fact that the private reward from invention efforts falls short of the social benefit. Consequently, private markets yield insufficient incentives to invent and innovate. This provides justification for government support of research and development.
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> The *pollution market failure* implies that, in the absence of fiscal or other forms of environmental regulation, prices of conventional, polluting production processes will be below their social cost. In the U.S., for example, the market penetration of clean,

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[8] More specifically, the curve relates per-capita income to emissions of various pollutants.

[9] The $7000-9000 figure is based on Grossman and Krueger (1995), converted to 2005 dollars.

hybrid cars has been made significantly more difficult because gasoline prices have been below social cost (Parry and Small, 2005), and thus the private cost of driving conventional cars is below social cost. Under-pricing of conventional technologies puts potential new and clean production processes or technologies at a competitive disadvantage, because the new technologies have to arrive at an exceptionally low cost in order to gain a market share. Thus, environmental regulation that helps put conventional technologies at their full social cost improves the competitive potential of new technologies, encourages innovation, and speeds up the arrival of cleaner technologies.

b. No matter when the new, clean technologies arrive, in the absence of vigorous environmental policy the nation will suffer excessive environmental damage during the time-interval from the present until this arrival time. Even before the new, clean technologies are invented, there is a role for vigorous environmental policy to encourage the "clean" use of *existing* technologies (for example, fuel-switching by electric generators, or use of energy-efficient appliances by consumers).

**b. Implications**

*Emissions taxes and tax-credits for emissions reductions*. What does this imply for China's use of fiscal instruments? With regard to the first two types of fiscal instruments mentioned – taxes on emissions or on polluting fuels, and tax-credits for pollution-reduction – it suggests more vigorous use of these instruments. To maximize the net benefits (environmental benefits minus regulatory costs from environmental regulation, emissions taxes should be set equal to the marginal environmental damage from emissions. Or, if tax-credits for cleaner production are employed, the tax-credit rate should be equal to this marginal damage.[10] However, China's current pollution levy rates are significantly below this rate (Goulder 2005).[11] For example, the statutory rate on sulfur dioxide is 0.365 RMB (or about $84 per metric tonne, using purchasing power parity) per kilogram, while estimates of marginal damages from sulfur dioxide are 3-8 times this value.[12] Raising the levy rates would produce benefits (in the form of avoided health costs and other adverse impacts on humans) in excess of the regulatory costs.

*Subsidies to research and development.* What are the implications for China's R&D policy? China devotes about 1.3 percent of its GDP toward R&D.[13] Of this, about a fifth is

[10] If emissions limits are employed, the level of allowable emissions should be such as to equate the marginal cost of reaching that limit with the marginal environmental benefit.

[11] Limited enforcement at the local level implies that the *effective* rates are considerably lower than this value.

[12] Pollution levy rates taken from http://www.x-rates.com/cgi-bin/hlookup.cgi. In calculating the marginal damages for China, I multiply estimates of marginal damages in the U.S. by the ratio of China's GDP to U.S. GDP. This assumes that willingness to pay for environmental improvement is the same proportion of national income in China and the U.S.

[13] http://en.chinabroadcast.cn/855/005/10/13/262@24499.htm.

energy- or environment-related R&D.[14] Table 2 shows the R&D and other innovation-related expenditures for China and other nations. The table indicates that China devotes a smaller share of its output to innovation-related work than the other countries listed – although it should be noted that China's commitment to R&D has increased significantly in recent years and that is per-capita income is less than that of the other listed nations.

Is China's commitment to R&D sufficient to fully correct the innovation market failure? It is difficult to say with certainty. However, the following statistic may suggest an answer. Several studies suggest that, in the U.S., the annual rate of return to energy-related R&D is over 25 percent -- several times the market interest rate or return on private-market investments.[15] This implies that the U.S. would benefit from devoting a larger share of its resources to energy-related R&D. Yet the U.S. already devotes a larger share of its GDP to R&D than does China. This suggests (but does not prove!) that China has significant untapped R&D resources and might also benefit from an expanded focus on R&D. Currently China's R&D policy gives considerable incentives to increase R&D *inputs.* Greater rewards for R&D results might improve the productivity of given expenditures on R&D. The structure of the incentive system can be as important as the total expenditure commitment.

## 6. Conclusions

Fiscal policies are an important element of the policy maker's toolkit for protecting the environment and encouraging efficient energy use. They have the potential to help bring the prices of goods and services closer to their full social cost – the private cost plus the external, environmental cost. This encourages cleaner production and consumption decisions and in theory enables society's to achieve the best balance between environmental quality and other valued goods and services such as affordable transportation and housing.

These policies have several attractions relative to other instruments for promoting energy efficiency or reduced pollution. In many instances, they enable society to reach given pollution-reduction targets at lower cost than would be possible through direct controls. They also tend to be more effective than direct controls in promoting the invention of new, cleaner energy technologies. And they can provide an efficient source of revenue to the government.

But the policies have some drawbacks as well. A key potential drawback is that they often impose a larger share of the overall policy cost on the polluting facilities. However, this disadvantage can be reduced or eliminated through judicious policy design. Another potential drawback is that the costs of fiscal policies may be more visible than those of direct controls.

Both emissions-oriented policies and "technology-push" policies (subsidies to R&D) are needed to achieve pollution reduction targets or energy-efficiency targets at the lowest cost to society. R&D support directly focuses on an "innovation market failure," while emissions policies focus best on the "pollution externality." And while fiscal approaches such as

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[14] www.863.org.cn/english/annual_report/annual_report_2002.pdf.

[15] See, for example, Department of Energy (1997).

pollution taxes or tax-breaks for pollution-reduction often have an advantage over direct controls for dealing with pollution externalities, direct controls such as efficiency standards or mandated technologies will have an advantage in some contexts – particularly when it is difficult to monitor emissions.

Finally, the presence of an "Environmental Kuznets Curve" does not offer a justification for China's postponing significant action to reduce pollution or encourage cleaner energy use. Even if China's per-capita income is below the critical income level beyond which, according to the EKC, environmental quality begins to improve, the nation is likely to benefit from expanded environmental protection in the present. Economic analysis indicates that in the absence of public intervention, private markets tend to generate excessive pollution in the sense that the social benefits from reducing pollution exceed the social costs of doing so. In addition, private markets tend to yield insufficient incentives to innovate: additional expenditures on R&D can be expected to yield social benefits in excess of the costs. Public policies to encourage innovation and to discourage pollution-intensive production methods can correct these market failures.

This has implications for China's current policy. China's current pollution levy rates are below the efficiency-maximizing rates (marginal environmental damages from emissions). Higher rates could produce environmental benefits in excess of the regulatory costs. In addition, China's share of GDP devoted to R&D is fairly low relative to other nations, although the share is growing significantly. Studies of the social return to R&D suggest that an increased commitment would produce social net benefits. The nature of the R&D support may be as important as the expenditure level.

These policies could include the various fiscal instruments discussed here as well as direct controls.

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## Table 1: Contributions of Environment-Related Taxes to Overall Tax Revenues for OECD Countries in 1997

| Country | Environment-Related Tax Revenue (millions of US dollars) | Total Tax Revenue (millions of US dollars) | GDP (billions of US dollars) | Environment-Related Tax Revenue as Percent of Total Tax Revenue | Environment-Related Tax Revenue as Percent of GDP |
|---|---|---|---|---|---|
| Austria | 4,865 | 91,297 | 206.7 | 5.33 | 2.35 |
| Belgium | 5,715 | 111,411 | 243.6 | 5.13 | 2.35 |
| Canada | 13,242 | 236,225 | 640.0 | 5.61 | 2.07 |
| Czech Republic | 1,501 | 20,460 | 53.0 | 7.33 | 2.83 |
| Denmark | 7,780 | 84,233 | 168.4 | 9.24 | 4.62 |
| Finland | 3,963 | 56,526 | 122.5 | 7.01 | 3.23 |
| France | 30,156 | 635,746 | 1,406.0 | 4.74 | 2.14 |
| Germany | 46,382 | 782,305 | 2,114.5 | 5.93 | 2.19 |
| Greece | 4,746 | 40,504 | 120.0 | 11.72 | 3.95 |
| Hungary | 1,292 | 17,868 | 45.8 | 7.23 | 2.82 |
| Iceland | | 2,377 | | | |
| Ireland | 2,381 | 25,772 | 78.5 | 9.24 | 3.03 |
| Italy | 37,790 | 515,237 | 1,159.5 | 7.33 | 3.26 |
| Japan | 71,388 | 1,202,355 | 4,195.3 | 5.94 | 1.70 |
| Korea | 13,333 | 101,880 | 476.9 | 13.09 | 2.80 |
| Luxembourg | 504 | 7,303 | 17.5 | 6.89 | 2.88 |
| Mexico | | 67,763 | | | |
| Netherlands | 13,668 | 158,109 | 376.7 | 8.64 | 3.63 |
| New Zealand | 1,108 | 23,553 | 64.9 | 4.70 | 1.71 |
| Norway | 5,570 | 65,676 | 155.0 | 8.48 | 3.59 |
| Poland | 2,350 | 55,936 | 143.2 | 4.20 | 1.64 |
| Portugal | 3,670 | 34,919 | 104.3 | 10.51 | 3.52 |
| Spain | 11,964 | 188,355 | 558.6 | 6.35 | 2.14 |
| Sweden | 7,276 | 122,252 | 237.5 | 5.95 | 3.06 |
| Switzerland | 5,020 | 86,729 | 256.3 | 5.79 | 1.96 |
| Turkey | 5,846 | 53,007 | 190.2 | 11.03 | 3.07 |
| United Kingdom | 38,247 | 464,383 | 1,315.7 | 8.24 | 2.91 |
| United States | 77,333 | 2,299,136 | 8,121.0 | 3.36 | 0.95 |
| **Total** | 417,090 | 7,551,318 | 22,571.6 | 5.52 | 1.85 |

***Source:*** **OECD**

## Table 2: Science Development Indicators

| Country | 1987-1997 R&D Expenditure as % of GNP | 1987-1997 No. of Scientists Engaged in R&D per Million | 1987-1997 No. of Technicians Engaged in R&D per Million | 1997 No. of Patent Applications per Million |
|---|---|---|---|---|
| | | | | |
| Australia | 1.80 | 3357 | 797 | 2342 |
| Denmark | 1.95 | 3259 | 2644 | 14076 |
| Finland | 2.78 | 2799 | 1996 | 12709 |
| France | 2.25 | 2659 | 2873 | 1681 |
| Germany | 2.41 | 2831 | 1472 | 1889 |
| Japan | 2.80 | 4909 | 827 | 3182 |
| Spain | 0.90 | 1305 | 343 | 2137 |
| Sweden | 3.76 | 3826 | 3166 | 9482 |
| United Kingdom | 1.95 | 2448 | 1017 | 2192 |
| United States | 2.63 | 3676 | - | 2342 |
| Mid-Income Countries | 2.00 | 2662 | 14439 | 5815 |
| China | 0.66 (1.31 in 2003) | 454 | 233 | 43 |

*Source:* WU Jinglian, "Which Path for Industrialization? A Choice for China." Presentation at inaugural conference for Center for Industrial Development and Environmental Governance, Tsinghua University, Beijing, China, September 28, 2005.

*Note:* Approximately a fifth of China's R&D is devoted to energy or environmental-treatment technologies (www.863.org.cn/english/annual_report/annual_report_2002/pdf).