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The Economics of Technology Diffusion: Implications for Greenhouse Gas Mitigation in Developing Countries

I N T E R N E T E D I T I O N

Allen Blackman • October 1997

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INTRODUCTION

Recent efforts to forge some consensus on the role that developing countries should play in reducing global greenhouse gas emissions have focused attention on climate friendly technologies (CFTs). Developing countries are expected to supersede industrialized countries as the leading source of greenhouse gas emissions in the next thirty years. Yet their ability and willingness to contribute to abatement efforts is constrained by limited financial resources, weak regulatory institutions, and the perception that they should not have to bear the costs of mitigating a problem primarily created by industrialized countries. CFTs are seen by many as a means of surmounting these obstacles.

Many types of CFTs — notably, energy efficiency innovations — not only reduce emissions of greenhouse gases but also cut production costs. As a result, such technologies could conceivably diffuse spontaneously in developing countries, obviating the need for government financing and regulation. Climate strategies that focus on promoting the diffusion of CFTs are likely to garner widespread support since they represent opportunities to enhance productivity and abate local pollution in the eyes of developing countries, and opportunities to boost exports of equipment and expertise in the eyes of industrialized countries.

But how likely is it that technology-based strategies will have a significant impact on greenhouse gas emissions in the near to medium term? In part, the answer depends on whether, once introduced, CFTs would diffuse at a reasonably rapid pace, and whether policy makers will be able to speed the rate of diffusion. This brief summarizes some of the key findings of the extensive economics literature on the diffusion of new technologies, and assesses the implications of these findings for the ongoing debate about technology-based climate change strategies. In short, the literature suggests that a wide variety of policies are likely to speed the diffusion of CFTs, including rationalizing energy prices, improving information, and investing in energy infrastructure.

THE ECONOMICS OF TECHNOLOGY DIFFUSION

Though not all the evidence on technology diffusion is conclusive, there is broad agreement on two points. First, new technologies are never adopted by all potential users at the same time. The widespread diffusion of new technologies can take anywhere from five to fifty years. Second, countless studies have confirmed that the diffusion of new technologies follows a predictable intertemporal pattern — technologies are adopted rather slowly at first, then more

rapidly, and then slowly again as a technology specific “adoption ceiling” is reached. These stylized facts have prompted researchers to focus on two related questions: Why do some firms adopt a given innovation before others? Why do some innovations diffuse more quickly than others?

Researchers have addressed these questions using a variety of theoretical constructs that emphasize different aspects of the diffusion process. “Epidemic” models focus on the dissemination of information about new technologies via day-to-day contact among firms, likening this process to the spread of a disease. These models imply that some firms adopt before others because they happen to become “infected” first, and that some innovations diffuse faster than others because they are more “contagious” than others by virtue of their profitability and limited riskiness.

So-called “rank” models are premised on the observation that, given differences in capital vintage, size, access to technical information, labor productivity, and environmental regulatory costs, some firms will get a higher return from a new technology than others. Hence, one may rank all potential adopters on the basis of their expected returns. Only firms with a sufficiently high ranking will adopt when an innovation first becomes available. However, over time — as sector-wide production and information costs fall, the new technology is refined, and the existing capital depreciates — lower ranked firms will adopt as well.

“Order” models are applicable when there is a fixed critical input into production such as a pool of specially trained labor or a scarce natural resource. In such situations, the order of adoption clearly matters — initially only first movers who secure access to the critical input will find it profitable to adopt.

Finally, so-called “stock” models are also premised on the idea that early movers obtain higher returns on the new technology. However, they attribute this phenomenon to the fact that as the stock of firms that have adopted a cost-saving innovation grows, average production costs fall, and eventually output prices fall as well. Thus, initially it will only be profitable for a limited number of firms to adopt.

It is important to note that these four types of theoretical models are not mutually exclusive. Indeed, the diffusion of any specific technology is likely to be influenced by some combination of the factors emphasized by the models: information and learning, the characteristics of potential adopters, the characteristics of technology, the scarcity of critical inputs, and the sensitivity of output prices to technological change.

Most empirical (versus theoretical) investigations of technology diffusion have sought to understand exactly how characteristics of new innovations and of potential adopters influence diffusion (thus, they essentially constitute tests of the rank model). They have found that, not surprisingly, relatively profitable, small-scale, and simple innovations are adopted fastest. In addition, they have found that new technologies are adopted fastest by firms that are large, have well-trained staff, incur high regulatory costs when using an existing technology, have infrastructure complementary to the new technology, are in fast-growing industries, invest more in R&D, pay relatively low prices for inputs used intensively by the new technology, and have relatively old existing capital. Despite considerable research, the evidence regarding the impact of market

structure (the degree to which the market is competitive or controlled by a small number of firms) on the timing diffusion is inconclusive.

POLICY PRESCRIPTIONS

What does the current state of knowledge suggest for technology-based climate change policy? Two implications are immediately obvious. First, even if CFTs that significantly lower production costs can be transferred to developing countries, diffusion will not be immediate. Second, developing country firms will not necessarily rapidly adopt CFTs simply because they reduce production costs in industrialized countries. A broad range of firm-level, sector-level, and country-level characteristics determine whether or not and how quickly new technologies are adopted, and there are likely to be systematic differences between developing countries and industrialized countries in nearly all of these characteristics. To give one example, labor is generally much less costly relative to capital in developing countries. Therefore, labor-saving technology that is profitable in industrialized countries will not necessarily be profitable in developing countries.

In addition, it is important to note that faster diffusion of a technology is not necessarily beneficial. As Stoneman and Dierderen point out (see Further Readings), diffusion may be “too fast” if firms adopt a technology before it is profitable to do so, or if firms adopt a new technology today that effectively preempts the adoption of a superior technology in the future.

Given the theory and evidence presented above, there would seem to be seven types of policy levers available to influence the speed of diffusion of CFTs in developing countries. These concern: information, input prices, regulation, credit, subsidies, human capital, infrastructure, research and development, and intellectual property restrictions.

Information. Economic theory suggests that the dissemination of information about the new technology is likely to be a critical determinant of diffusion. (Limited empirical support for the importance of information probably stems only from the difficulty of measuring information flows.) As Stoneman and Dierderen make clear, government intervention to enhance the dissemination of technical information is likely to be justified since virtually every means by which firms acquire information about new technologies is imperfect.

When firms acquire technical information through day-to-day contact with other firms, early adopters supply information about the new technology to later adopters, but the former do not capture any of the benefits from this information transfer themselves. As a result, they do not have proper incentives to make this information available to their rivals. When firms acquire technical information through active search, firms operating independently will engage in inefficient duplication of search efforts. And finally, when firms acquire technical information from advertising, technology suppliers who are concerned about market share, not the diffusion of the technology, have incentives to oversupply technical information, which may lead to too-rapid diffusion of intermediate technology.

Policy options for enhancing the flow of information about new technologies include demonstration projects, advertising campaigns, the testing and certification of new technologies,

and subsidies to technological consulting services. Have such mechanisms had a verifiable impact on diffusion? Demonstration projects have received wide application in the context of developing country agriculture, and many industrialized countries have set up regional information clearinghouses to provide consulting services to small- and medium-sized businesses that presumably can least afford search costs associated with adoption. As yet, however, evaluations of these programs have been limited, and we know little about their effectiveness.*

Finally, it is worth noting that information-based policies may actually retard diffusion by fostering the expectation that improved technologies are forthcoming, and therefore creating incentives to defer adoption. A similar problem arises when public provision of information about new technologies crowds out private information.

Input Prices. Both theory and evidence attest to the important role that input prices play in the diffusion of new technologies. In particular, energy prices clearly have a critical impact on the adoption of energy saving technologies. In a number of developing and reforming economies, energy is still subsidized. Removing or significantly scaling back energy subsidies in these countries would create strong incentives to adopt energy-saving technologies. In countries where energy prices are not subsidized, taxing energy to raise its effective price above the market price would have the same effect as removing subsidies.

Regulation. As noted above, empirical research supports the hypothesis that firms subjected to stricter environmental regulation are more likely to adopt clean technologies, including CFTs. The opportunities for, and barriers to effective regulation in developing countries have received considerable attention, especially in the last ten years. Two points deserve mention. First, the use of market-based incentives such as pollution taxes and marketable permit systems — including a credible international greenhouse gas emissions trading system — is analogous to raising the price of a critical factor of production, namely environmental services. Therefore, the same arguments about the link between factor prices and technology adoption are applicable. Second, even when institutional and financial constraints make formal public-sector-led regulation problematic, private-sector-led “informal” initiatives (such as grassroots efforts to deter polluters by stigmatizing them) can be an effective substitute.

Credit. Lack of access to credit may be a critical barrier to adoption. Subsidizing credit for specific types of investments has been a common policy response. However, thus far these programs — both public and private — have had very mixed results. Chronic problems include the diversion of loans by borrowers to non-targeted activities, low repayment rates, the creation of financially unsustainable lending institutions, politicization of lending decisions, and the undermining of existing credit markets. Since there is growing support for the view that the costs of “targeted” credit outweigh the benefits, a wiser approach to overcoming financial barriers to technological innovation is to focus on improving banking which, in developing countries, is often hamstrung by unstable monetary policy, interest rate restrictions, and weak property rights.

* For example, the US Department of Commerce sponsors a network of “Manufacturing Technology Centers.” Similar networks have been established in the United Kingdom (the Advanced Information Technology Programme, and the Regional Office Technology Transfer Programme), in France (Centres Regionaux d’Innovation et de Transfer de Technologie), and in the European Union (the SPRINT programme).

Subsidies. An obvious mechanism for speeding the diffusion of a new technology is for governments to subsidize it. But subsidies, in addition to being quite expensive, are likely to be subject to many of the same problems as targeted credit, namely the politicization and distortion of input markets.

Human Capital, Infrastructure, and Research and Development. Empirical research on the links between early adoption of innovations on the one hand and human capital, infrastructure, and research and development (R&D) on the other suggests there is an argument for subsidizing education, technical training, infrastructure and R&D. This needn't be a broad-brush strategy if these subsidies are focused on greenhouse-gas-intensive sectors such as energy.

Intellectual Property Restrictions. Intellectual property restrictions such as patents and licenses have countervailing effects on technology diffusion. On the one hand, they stimulate R&D, which in turn stimulates technology diffusion. Perhaps more important for developing countries, they are likely to encourage foreign investment, which can be a significant source of new technologies. But on the other hand, intellectual property restrictions attach significant costs to adoption of new technologies which can retard diffusion. In many developing countries, adaptation of existing technologies, rather than the creation of substantially new ones, accounts for the bulk of productivity growth. Therefore, there is reason to suspect that the negative impact of intellectual property restrictions on diffusion in developing countries could be substantial.

PRACTICAL FIRST STEPS

Of the broad range of policy options presented here, which are likely to be politically practical? As mentioned in the introduction, technology-based strategies will generate political support to the extent they represent obvious “win-win” opportunities for the parties involved. Many of the policies described above fit this description to some degree. Information, human capital and infrastructure policies will enhance productivity; rationalizing energy prices will boost allocative efficiency; improving banking should stimulate saving and investment; and strengthening regulation should produce environmental benefits.

However, some of these policies involve up-front economic costs that are more immediate and payoffs that are more delayed than others, making them unattractive to decision makers with short time horizons. For example, though investments in banking, human capital (broadly defined), and environmental regulation may have tremendous benefits in the long run, they involve substantial up-front costs. Thus, the most practical policy options discussed here would seem to be rationalizing energy prices, improving information, and investing in energy infrastructure.



FURTHER READING

General Interest

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About Resources for the Future

Resources for the Future (RFF) is an independent, nonprofit research organization that aims to help people make better decisions about the conservation and use of their natural resources and the environment. For the past 45 years, researchers at RFF have conducted environmental economics research and policy analysis involving such issues as forests, water, energy, minerals, transportation, sustainable development, and air pollution. They also have examined, from a variety of perspectives, such topics as government regulation, risk, ecosystems and biodiversity, climate, hazardous waste management, technology, and outer space.

While many RFF staff members are economists by training, other researchers hold advanced degrees in ecology, city and regional planning, engineering, American government, and public policy and management. RFF neither lobbies nor takes positions on specific legislative or regulatory proposals. Its operating budget is derived in approximately equal amounts from three sources: investment income from a reserve fund; government grants; and contributions from corporations, foundations, and individuals (corporate support cannot be earmarked for specific research projects). Some 45 percent of RFF's total funding is unrestricted.

The latest RFF news and information is available on the internet at <http://www.rff.org>.

About RFF's Climate Economics and Policy Program

As international debate intensifies over possible agreements to limit emissions of greenhouse gases, Resources for the Future (RFF) launched its Climate Economics and Policy Program in October 1996 to increase understanding and knowledge of the complex issues that must be addressed to design appropriate domestic and international policies that are effective, reliable, and cost-efficient. The program responds to both the long-term debate about climate change, and the specific debates surrounding the negotiations being carried out under the United Nations Framework Convention on Climate Change.

RFF brings a well recognized and respected reputation for objectivity to this debate. The Climate Economics and Policy Program integrates the many different aspects of climate change with ongoing basic and applied research at RFF involving energy markets, water and forest resource management, air pollution, environmental regulation, and sustainable development.

Drawing on RFF's strengths in environmental and natural resource assessment, economic analysis, and policy design, the climate program focuses on five main areas: economic and environmental consequences of climate change and policies to deal with climate change; domestic and international policy design issues; interactions between climate change and other policies; equity, efficiency, and other criteria used in decisionmaking; development of analytical tools.

PROGRAM OUTPUTS. RFF's climate program includes original basic and applied research, policy analysis, and educational outreach.

Research. Integrating basic and applied research on the economic implications of global climate change with ecological, engineering, scientific, environmental health, geographical, international, and other considerations, an initial set of research projects underway at RFF include:

- Bringing Uncertainty into the Equation When Calculating Climate Change Risks
- Discounting in Intergenerational Decisionmaking (workshop)
- Economic Analysis of Greenhouse Gas Emissions Trading
- Effective Environmental Policy in the Presence of Distorting Taxes
- Electricity Restructuring and the Costs of Controlling CO₂
- Environmental Consequences of Tax System Reform
- Impacts of Climate Change Mitigation on Other Environmental Problems
- Importance of Technical Change in the Economics of Carbon Policy (workshop)
- International Cooperation for Effective and Economic Greenhouse Gas Limitation
- Vulnerability of Low-Income Households to the Hydrologic Effects of Climate Change

Policy analysis. As a response to questions arising in the ongoing international negotiations, RFF will issue a series of short papers on a variety of issues related to policy in 1997. These studies will be based on original research combined with critical reviews of existing literature. Potential questions to be addressed include:

- How should the climate problem be thought about in general?
- How might a domestic emissions trading program be established?
- How does the performance of revenue-raising and non-revenue-raising policy instruments compare?
- How should emissions reductions be scheduled over time?
- What is the potential for technical innovation to substantially lower the cost of greenhouse gas limitations, and what government policies can tap that potential?
- What are the strengths and weaknesses of different modeling approaches for assessing the economic costs of greenhouse gas limitations?

Educational outreach. RFF regularly shares its climate change findings with members of the academic, business and environmental communities, and representatives of local, national and international governments by publishing and disseminating discussion papers and convening educational forums on selected topics. To support a well-informed public, RFF provides regular reports of its climate change activities to the news media, posts program updates and activities on RFF's internet home page (<http://www.rff.org>), and recently launched *Weathervane*, an internet site devoted to the discussion and debate of climate change policy (see next page for more information).

Looking for an honest broker for climate change policy?

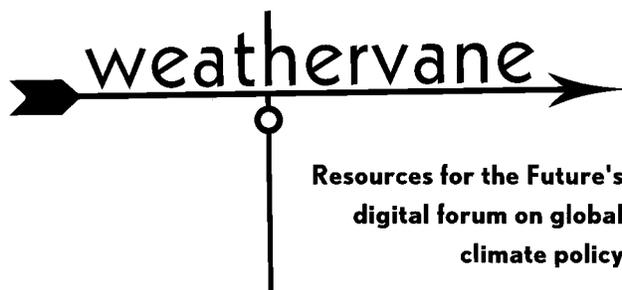
In light of the continuing international negotiations over climate change, Resources for the Future (RFF) publishes *Weathervane*, an internet forum dedicated to climate change policy. Just as a traditional weathervane tracks the direction of the wind, *Weathervane* has been tracking developments in climate change policy, both internationally and within the United States, since July 1997.



Our editorial aim is to present balanced and objective information, with no one perspective or viewpoint dominating our analysis and reporting. Now with an eye on the Fourth Conference of Parties, to be held in Buenos Aires, Argentina in November 1998, and the stakes potentially enormous on all sides of this complicated issue, *Weathervane* continues to provide a neutral forum for careful analysis to complement the political calculations that so often drive decisions.

Regular site features include:

Perspectives on Policy, an opinion forum for invited players in the climate policy debate. It gives experts from every corner — business, government, environmental groups, and academia — an opportunity to weigh in with their opinions on a selected topic; *By The Numbers*, a regular column by RFF's Raymond Kopp to help decode and demystify energy and environmental data and create a better understanding of the link between economic data and policy formulation; *Enroute to Buenos Aires*, which tracks developments in global climate change policy and players in the debate; *Research Spotlight*, which reports new climate findings and projects; and *Sounding Off*, an open forum for site visitors to voice their opinions on a variety of topics related to climate change.



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