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An "Adequate Insurance" Approach to Critical Dependencies of the Department of Defense

Benjamin Zycher, Kenneth A. Solomon,
Loren Yager

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The research described in this report was sponsored by the Defense Advanced Research Projects Agency. The research was conducted in RAND's National Defense Research Institute, a federally funded research and development center supported by the Office of the Secretary of Defense and the Joint Staff, Contract No. MDA903-90-C-0004.

Library of Congress Cataloging in Publication Data

Zycher, Benjamin.

An "adequate insurance" approach to critical dependencies of the Department of Defense / Benjamin Zycher, Kenneth A. Solomon, Loren Yager.

p. cm.

"Prepared for the Defense Advanced Research Projects Agency."

"R-3880-DARPA."

Includes bibliographical references.

ISBN 0-8330-1143-X

I. United States—Armed Forces—Procurement. I. Solomon, Kenneth A., 1947– II. Yager, Loren, 1954– III. United States. Defense Advanced Research Projects Agency. IV. Title. UC263.Z93 1991 355.6'212'0973—dc20 91-13816 CIP

The RAND Publication Series: The Report is the principal publication documenting and transmitting RAND's major research findings and final research results. The RAND Note reports other outputs of sponsored research for general distribution. Publications of RAND do not necessarily reflect the opinions or policies of the sponsors of RAND research.

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91-08865

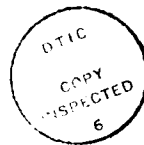


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PREFACE

This report is one of several prepared for the Defense Advanced Research Projects Agency on the issue of foreign dependencies of the Department of Defense. The central goals of the report are development and illustration of a methodology for analysis of "vulnerabilities" purportedly yielded by those foreign dependencies. The report discusses the nature of "insurance" in this context, and examines the distinction between "dependence" and "vulnerability." The approach is illustrated with analysis of issues of particular concern to the Department of Defense. The report should prove of interest to policymakers and others concerned with defense preparedness, the defense industrial base, foreign dependence, and the allocation of defense functions among the private, public, and foreign sectors. The work was carried out in the International Economic Policy Program of the National Defense Research Institute, RAND's federally funded research and development center supported by the Office of the Secretary of Defense and the Joint Staff.



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SUMMARY

The vast array of Department of Defense (DoD) activities and acquisitions guarantees that some resources and activities can be obtained or undertaken more cheaply from foreign suppliers than domestic ones. This dependence upon foreign suppliers, materiel, and (embodied) technology raises the issue of the future security of DoD operations in the face of various kinds of interruptions. However, acquisition of resources from either domestic or foreign sources can be subject to interruption. This means that dependence, whether domestic or foreign, leads the U.S. economy generally and the Department of Defense in particular to obtain various kinds of insurance, of which stockpiling is but one simple example.

Acquisition of such insurance may be adequate or inadequate in any given case depending upon specific circumstances. "Adequate" insurance is not "complete" or "perfect" insurance; instead, it is an amount that equates the marginal cost of obtaining it with the expected marginal benefits thus acquired. The central question to be asked with respect to any given dependence, foreign or domestic, is whether incentives to provide or obtain adequate insurance are biased downward. To the extent that inadequate insurance is forthcoming in any given case, a true "vulnerability" can be said to exist.

Such inadequate incentives can afflict both foreign and domestic sources of insurance or dependencies. The usual assumption is that foreign dependence is the more dangerous; this must rest upon an implicit belief that insurance is less likely to be adequate in the case of foreign dependence. That implicit assumption is plausible but far from self-evident, even if foreign dependence is subject to more or more varied interruptions. If incentives or opportunities for the provision of insurance are biased downward domestically, relative to those overseas, then domestic dependence ironically may yield the greater vulnerability.

Insurance of various kinds can be provided by the private sector, the government, or by foreigners. With respect to each potential source, two questions must be asked: (1) What factors might hinder the provision of adequate insurance? (2) What conditions might reduce or eliminate the adverse effects of those factors? Several factors can lead to inadequate provision of insurance by the private sector. An **expectation of price controls** on the insurance would bias downward current incentives to invest in it. **Public sector**

monopsony—an expectation that those providing the insurance will have no one with whom to deal except the government—would bias incentives downward because the expected monopsonistic behavior would reduce future prices. **The corporation income tax** induces the corporate sector to use a discount rate higher than the “social” rate, thus reducing corporate interest in provision of insurance for contingencies that are distant in time. Various kinds of **regulatory policies** can increase the cost or difficulty of insurance provision by the private sector. **Difficulty in writing or enforcing some kinds of contracts** can have the same effect. **Cost-plus contracting** by the Department of Defense can reduce incentives by denying firms providing insurance the future market (or replacement) value of the assets, particularly if the insurance assets have values that tend to rise over time. Finally, **poor information** about future contingencies or about attendant DoD concerns can lead the private sector to eschew insurance investments that otherwise might be undertaken.

For the government sector, two important disincentives are present. First, government decisionmakers may, because of short tenures in office, display **short time horizons**. Second, the government may be led by political pressures to **emphasize programs yielding important benefits to concentrated interest groups**, and to de-emphasize programs yielding benefits that, while important, accrue to the nation as a whole rather than to specific interests. Defense in general may embody more of such “collectiveness” than non-defense programs, and defense insurance may in some cases reflect these conditions as well.

Foreign providers of insurance may be immune from the considerations noted above but may face disincentives of their own. Apart from the possibility that **foreign governments may proscribe delivery of insurance to the United States during future contingencies**, access to the insurance may be problematic due to **potential interdiction**. If this is foreseen by the foreign providers, then their incentives to invest in the insurance currently are likely to be inadequate.

Four examples are discussed in this report as a means of applying the analytic framework and of examining the factors that are correlated with vulnerability as defined above. **Tritium** is a crucial component of U.S. nuclear weaponry, for which our supply sources are entirely domestic. Nonetheless, an important vulnerability has arisen, because the producing facilities have been shut down for a variety of reasons even as regulatory and other constraints have prevented the private sector from providing insurance. Acquisition of foreign supplies is problematic, and the long lead times combined with other factors have led the government not to provide adequate

insurance. In short, complete domestic dependence has not prevented vulnerability, which, in turn, may lead to foreign dependence if foreign tritium supplies are needed as substitutes in the short term.

Surface acoustic wave (SAW) technology has many military applications in radar, naval communications, and in pressure and temperature sensors. Transistors and oscillators can be substituted for SAW devices in many applications, with efficiency losses ranging from slight to substantial. Foreign dependence for SAW devices has been growing and now is about 75 percent; however, substantial domestic capacity remains and could be expanded relatively quickly. Monopsony and other disincentives are not important. In short, current incentives for insurance appear adequate; increasing foreign dependence has not yielded vulnerability.

Dynamic random access memory (DRAM) chips provide the working memory in computers and other information processing equipment. Close substitutes are not available, although different generations of DRAM chips can substitute for each other. Military use of DRAM chips is small relative to commercial use; the number of U.S. firms producing the chips has fallen sharply, although substantial U.S. capacity remains, particularly if production by IBM is counted. Because DRAM chip prices have tended to fall sharply over time, stockpiles of chips or surge production capacity are expensive. This suggests that the amount of insurance that the market will provide is small, although the much larger commercial market may constitute insurance from the DoD viewpoint. Several other factors—such as risk aversion on the part of DoD and information problems—may distort downward the amount of insurance provided by the private sector. These considerations suggest that incentives for provision of insurance appear less adequate than in the SAW technology case.

High-definition television (HDTV) is a range of emerging technologies producing a television picture with improved clarity on screens larger than currently in widespread use. In particular, picture resolution would be improved on the larger screens. Prospects for development of a sizable commercial market are problematic. Production of HDTV components is likely to take place overseas, particularly in Japan, with a good deal of the final assembly conducted in the United States. Conventional electronic components are good substitutes for HDTV, and U.S. production capacity for these substitutes is substantial. Under the assumption that conventional components are not good substitutes in military applications, private sector investment in HDTV insurance is problematic. Monopsony and other considerations are likely to be important, and investments probably

would be viewed as long-term. Governmental disincentives seem less important, and so the government may prove to be the main source of insurance for HDTV use in military applications.

These examples suggest that foreign dependence by itself is not the major factor determining vulnerability, unless access to foreign insurance itself during future contingencies is viewed as problematic. More important factors seem to be the presence or absence of disincentives for investment in insurance, the availability of substitutes, and the presence of a sizable commercial market for the goods in question. Thus, foreign dependence by itself does not yield vulnerability and may offset vulnerability caused by domestic conditions.

The Department of Defense should view such factors as those discussed in this report as warning signals of potential inadequate insurance. Further research should examine these sources of inadequate insurance more extensively and in greater detail. A better definition and means of measuring insurance are needed. And further research should apply the analytic framework to a greatly expanded sample of DoD dependencies.

Many of the sources of inadequate insurance can be rectified only by Congress, and even some of these potential reforms may not be viable over time. However, DoD can write contracts in ways yielding greater confidence on the part of private investors that such investments will prove profitable. Alternatives to cost-plus contracting should be investigated. Above all, DoD can focus attention upon the true sources of vulnerability rather than the narrow foreign/domestic dependence dichotomy that has been emphasized far more commonly.

ACKNOWLEDGMENTS

A number of colleagues provided suggestions yielding a much improved report. Arthur Alexander, C. R. Neu, and Maurice Eisenstein, all of RAND, provided detailed reviews of the manuscript. Additional comments were offered by Gregory Hildebrandt and Charles Wolf, Jr., of RAND, and by David Henderson of the Naval Postgraduate School, Martin McGuire of the University of Maryland, and William A. Niskanen of the Cato Institute. We are indebted to all of them.

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I. INTRODUCTION

SOME DISTINCTIONS AMONG DEPENDENCE, INTERRUPTION RISK, AND VULNERABILITY

The worldwide operations of the Department of Defense (DoD) inevitably include dependence upon both domestic and foreign sources of raw materials, equipment, inputs, components, technology and associated expertise, and other important goods. As the economies of Japan, Western Europe, and the Pacific Rim have grown, this dependence upon foreign sources of defense goods, however measured,¹ is perceived to have increased, thus raising in the minds of many the prospect of various kinds of interruptions over which the United States has reduced control. And as weaponry and other defense goods grow over time in technical sophistication, increasing foreign competition in technological developments raises the specter of a U.S. defense establishment increasingly hindered in its efforts to offset perceived numerical inferiority with superior technology.

In short, the vast array of DoD activities and acquisitions—combined with technological progress and increased production capacity abroad—guarantees that some resources and activities can be obtained or undertaken more cheaply from foreign suppliers than domestic ones. This dependence upon foreign suppliers, materiel, and (embodied) technology raises the issue of the future security of DoD operations in the face of various kinds of interruptions. Broadly interpreted, the security problem includes not only the possibility of short-term stringencies, but also possible adverse effects upon the U.S. technological “learning curve” of current dependence upon foreign transactions.

Now, acquisition of resources from *either* domestic or foreign suppliers can be subject to interruption, although foreign dependence may be subject to more and more varied adverse events because of distance, reduced political stability, perceived international leverage, military contingencies, and other considerations. But neither would complete domestic dependence—autarky—be immune from interruption risks,

¹The difficulty of measuring “the extent of the Pentagon’s dependence on foreign sources in critical areas” is noted in a recent article in *Aerospace Daily*. Also noted is a great reliance upon anecdotal evidence. See “Policy-Makers Have No Way To Assess Industrial Base Problem,” *Aerospace Daily*, July 20, 1989.

even apart from its great cost. For example, complete autarky—say, in energy supply—would not eliminate the risk of such types of interruptions as pipeline ruptures. Different patterns of domestic and foreign acquisition, or dependence, thus imply different patterns of interruption risk for any particular good valued by the Department of Defense.

This prospect of interruption or other adverse events leads the U.S. economy generally and DoD in particular to acquire various kinds of insurance, of which stockpiling is but one simple example. The next section discusses in more detail the broad nature of “insurance” in the context of Department of Defense foreign dependencies. Acquisition of such insurance by DoD, or by the private sector in anticipation of possible future needs, contingencies, and opportunities, may be adequate or inadequate in any particular case depending upon specific circumstances. “Adequate” insurance is not complete or perfect insurance; in any given case it is sensible to accept some “vulnerability” (that is, some risk of substantial damage caused DoD operations by an adverse event) because in a world of uncertainty the cost of reducing it further exceeds the expected benefit of doing so. Instead, adequate insurance is an amount that equates the marginal costs of the insurance with the marginal benefits that the insurance is expected to provide by compensating for or reducing contingent losses. These latter benefits include *current* risk reduction offered by various forms of insurance. This reduction in risk may be more valuable to DoD than is perceived by potential providers of insurance, whether domestic or foreign. If the interruption risk posed by a given foreign dependence is insured adequately (or “optimally”), then it does not present a true “vulnerability” problem.

Thus, “vulnerability” while certainly affected by patterns of acquisition—that is, dependence—and attendant interruption risks, itself is *determined by the degree to which those risks can be or are insured adequately*. To say that the United States can exert greater “control” over defense acquisition that is domestic rather than foreign² is to say—or assume—that it is easier or less expensive to insure adequately against the adverse effects of domestic interruptions than those caused by foreign ones. In other words, the conventional assumption—which usually is implicit rather than stated explicitly—is that *constraints hindering acquisition of adequate insurance against interruptions and their adverse effects are greater*

²Although not usually defined in a measurable way, the greater “control” inherent in domestic acquisition—and the greater “vulnerability” presented by foreign dependence—are assumed very widely in the policy literature. See, for example, Defense Science Board, *The Defense Industrial and Technology Base* (Final Report of the Defense Science Board 1988 Summer Study), Vol. I, October 1988.

or more difficult to overcome when dependence is foreign rather than domestic. But that assumption, while certainly plausible, is far from self evident. Even if foreign dependence, for any given defense good, is subject to more or more varied kinds of interruptions, it does not follow that insurance necessarily is easier to obtain in the domestic context. To the extent that it is easier in any given case to insure against the possible contingencies presented by foreign dependence than by domestic acquisition, greater foreign dependence ironically may carry reduced vulnerability.

The real possibility of an inverse relationship between foreign dependence and vulnerability exists because insurance against interruptions or an erosion of technological advantage must be provided by someone, whether in the private sector or by the government itself. *If, for some reason, incentives or opportunities for the provision of insurance are biased downward domestically, relative to those overseas, then domestic dependence, even if subject to fewer potential interruptions, may cause greater dislocation should an interruption occur.* In a word, it would imply greater vulnerability.

A simple example may be useful at this point. Consider the acquisition of crude oil by DoD or by the U.S. economy as a whole. It is likely to be the case that foreign sources of crude oil—foreign dependence—are subject to more and more likely types of potential future supply disruptions than is domestic production.³ Foreign oil fields can be subject to official or unofficial shutdown, labor or political unrest, or unavailability caused by regional armed conflict. Transportation of foreign oil covers long distances and typically involves several modes, such as pipelines, ships, port terminals, and perhaps trucking. Thus, at first glance, it may seem to be the case that dependence upon foreign oil carries greater vulnerability than does dependence upon domestic sources of oil, a view expressed quite commonly in the popular literature.⁴

As noted above, however, the real issue is the relative magnitude of constraints affecting the availability of insurance against domestic

³For an illustration of the interruption potential inherent in domestic crude-oil dependence, one need look no further than the recent Exxon Valdez accident involving Alaskan North Slope crude oil.

⁴An example is the DOE National Energy Plan (U.S. Department of Energy, *National Energy Plan II: A Report to the Congress Required by Title VIII of the Department of Energy Organization Act*, May 1979). Note that the economic effects (except aggregate wealth effects) of oil supply disruptions are the same in the cases of foreign and domestic oil dependence, because an oil supply disruption would have the same effect upon the cost of oil acquisition to the U.S. economy regardless of the sources of oil used domestically. See Benjamin Zycher, "Emergency Management," in S. Fred Singer (ed.), *Free Market Energy*, Universe Books, New York, 1984.

and foreign oil supply disruptions, respectively. Ordinarily, one would expect the private sector to foresee the possibility of supply disruptions from either source, and prepare in advance, as a means of capturing the higher market value of oil during the disruption. The same is true for the Department of Defense. Among the ways available to do that are diversification of sources, excess production capacity, or stockpiling as means by which the adverse impact of any given supply disruption can be "diluted." While this may seem straightforward for both domestic and foreign supply sources, past U.S. policy has erected a perverse incentive in the domestic case. Since binding price controls were enforced in both 1973 and 1979, it is likely to be the expectation of the market that similar controls might be imposed in the event of a future disruption causing a sharp increase in price.

This means that potential domestic producers of alternative supplies—insurance—face some prospect that the future earnings from their investments will be confiscated in part during a future contingency. This increases the difficulty of obtaining such insurance domestically, but not overseas, since U.S. price controls cannot be enforced internationally. Thus, ironically, insurance against oil supply disruptions may be easier to obtain from foreigners than domestically, meaning that it is domestic dependence that under some conditions may carry greater vulnerability.⁵ Such insurance might take the form of diversification of supply sources, which, given the prospect of price controls enforced domestically, but not internationally, might be easier to achieve among foreign producers. These problems, caused by the expectation of price controls on oil, have led the federal government to establish and expand the Strategic Petroleum Reserve (SPR), which contained about 575 million barrels as of September 1989. Obviously, the SPR itself is a form of insurance, created with foreign supply disruptions in mind, but which is available in the event of any disruption. It substitutes for the private insurance investments that would be made in the absence of the regulatory disincentives.

In short, this report has as one goal development of a method of analyzing the vulnerability problem that will facilitate the efforts of DoD to seek, discover, and offset critical vulnerabilities. The first issue to be addressed, then, is that of directing DoD's attention: among the myriad dependencies of the Department of Defense, where

⁵For example, a contract for delivery/purchase of crude oil might include a requirement for excess production capacity or for standby supplies. Such contracts, because of the incentives provided by expected price controls, may be easier to write and enforce internationally than domestically.

should limited time, attention, and resources be applied in efforts to find and ameliorate critical vulnerabilities? In other words, for what signs or "flags" of potential vulnerability should DoD be on alert? In what specific instances, or types of instances, are current conditions likely to yield underinsurance against supply disruptions?

The second part of the report examines four dependence examples as a means of gaining additional insight into the factors likely to be correlated with vulnerability as defined above, and thus likely to serve as useful targets for DoD attention.

ORGANIZATION OF THIS REPORT

Section II outlines varying aspects of "interruption" and "insurance" in the context of foreign dependencies of the Department of Defense. Section III presents a taxonomic discussion of factors that may yield disincentives for the domestic private and public sectors and for foreigners to provide adequate insurance despite interruption risk. The definition of "foreign" dependence is explored briefly in the vulnerability context. Section IV applies the analytic framework to four examples—tritium, surface acoustic wave (SAW) technology, dynamic random access memory (DRAM) chips, and high-definition TV (HDTV)—as a means of illustrating the approach and of gaining insights into the critical relationships. Finally, Sec. V offers conclusions and an agenda for further research.

II. SOME ASPECTS OF INSURANCE IN A FOREIGN DEPENDENCE CONTEXT

As noted in Sec. I, acquisition of resources and materiel from either domestic or foreign suppliers is a process subject to interruptions that can vary greatly in type, magnitude, duration, amenability to offsetting factors or actions, and other important characteristics. To put it differently, the acquisition of defense goods, whether from domestic suppliers or overseas, is subject to a wide variety of risks.⁶ These risks can vary along a number of such dimensions as the following:

- The type or source of disruption.
- The duration of the disruption.
- Available responses to the disruption.
- Varying sets of physical, economic, and political conditions (scenarios) under which the disruption occurs.

Some examples may be of use at this point. Disruptions clearly can vary by source—acts of God in the form of earthquakes, floods, and other events can interfere with earthly endeavors. Such political acts as blockades, military actions, embargoes, and terrorist attacks can disrupt the flow of resources and materiel. The same can be said for certain kinds of economic events—strikes, weather-related supply reductions, and short-run constraints in production capacity. And it is clear that differing goods *and differing supply sources* are likely to be associated with differences in the types and probabilities of various kinds of disruptions. In particular, foreign acquisition may be subject to potential interruptions that are different, more frequent, and more varied than domestic acquisition of similar goods.

Just as the sources of potential disruption vary widely, so do the differing forms of “insurance” available at least in principle to ameliorate the potential effects of adverse events. In anticipation of potential adverse events, actions can be taken to reduce the probability of disruption; an example is physical security protection for production facilities to reduce the likely effects of fires, earthquakes,

⁶We put aside here the analytic issues inherent in measurement of risk and the complications introduced by the distinction between risk (uncertainty about the actual outcomes to be experienced or “drawn” from a known distribution of possible outcomes) and uncertainty (uncertainty about outcomes drawn from an unknown distribution of possible outcomes). Such issues would complicate the analysis considerably without contributing to understanding of the policy context of interest here.

terrorist attacks, and similar events. Alternatively, terrorist organizations can be bribed to eschew attacks on given facilities or interests. Other actions can be undertaken in efforts to reduce the adverse effects of a disruption in the event that one takes place. Thus, stockpiles and other sorts of buffer stocks can be acquired for use in the event of an "emergency." Alternative suppliers, sources, transport routes, and similar substitutes can be arranged in advance of interruption. Or investments can be made in the availability of services designed to minimize losses in the event of fire or other disruptions. Another insurance method, perhaps more familiar, simply arranges for financial compensation in the event of loss from specified adverse events.

Thus, insurance can be viewed as a series of alternative or complementary investments designed to mitigate the effects of future events that are uncertain in timing, magnitude, frequency, and duration. The common thread among such potential future events is their impact upon the value of the resource affected adversely: by disrupting supplies, they raise the value of the good. An investment in insurance, in effect, attempts to shift resources from the period of nondisruption, during which the resources have a relatively low value, to the disruption period, during which the resources acquire a relatively higher value.

This means that investment in various types of insurance is economic if the value of the resources being insured is expected to rise between the time of investment and the time of disruption at a rate at least equal to the market rate of interest, adjusted for risk.⁷ Thus, the decision to invest in insurance in anticipation of any of a number of types of disruptions is dependent crucially upon expectations about the types, magnitudes, timing, duration, and frequency of the future disruptions. A two-minute delay of a supply truck at a traffic light is a disruption, but it is unlikely to be of any importance because its effects upon the value of the related resource are close to zero. On the other hand, a potential lengthy shutdown of a pipeline may, prospectively, raise the possibility of losses sufficiently large to make economic an investment in insurance. Or, it may not; in some cases the cost of insurance and the expected effects of interruption may lead to a decision to deal with a potential interruption if and when it actually occurs. In short, not all potential interruptions are worth insuring. The "insurance" problem, then, can be viewed as an effort

⁷After all, the resources invested in insurance could be invested in other activities; in order to be competitive, the insurance investment must offer expected returns at least equal to those prospective in other investments.

to compare the costs of various kinds and sizes of current insurance investments with the costs that can be expected, with whatever degree of uncertainty, to be attendant upon future adverse events. Thus, the insurance problem involves the allocation of resources among alternative responses to uncertainty in a way that balances expected benefits and costs.⁸ To put it differently, the analytic problem is the choice of alternative investments that are designed to mitigate interruptions in ways that minimize expected losses, including the costs of insurance itself.

This report does not attempt to map correlations between foreign and domestic acquisition, on the one hand, and types, durations, and other characteristics of disruptions on the other. Instead, this report begins with the straightforward recognition that any type of insurance requires prior investment. More to the point, incentives to acquire (or provide) adequate insurance depend upon a perception of the requisite future benefits by those deciding whether or not to make the investments. Thus, for investments in insurance in anticipation of disruptions from *either* foreign or domestic suppliers to be adequate, incentives—that is, perceived benefits—must not be biased downward. This report considers conditions facing potential private, governmental, and foreign providers of insurance in the context of DoD acquisitions that might bias these incentives downward. This would yield inadequate insurance, or, as termed here, *vulnerability*.

⁸This formulation assumes neutrality with respect to risk as a simplifying stance. Assumption of risk aversion would not change any essential conclusion.

III. SOME SOURCES OF INADEQUATE INSURANCE

Before turning to the insurance issue itself, it is useful to digress briefly upon the nature of the problem posed by "foreign" dependence. As noted above, acquisition of defense goods from overseas itself says little about the ability to insure against adverse events, a parameter distinct from the relative number and variety of supply disruptions expected to afflict domestic and foreign dependence. Even a casual review of the literature reveals a fear of foreign dependence that is widely held but thinly supported in specifics.⁹ Precisely *why* does foreign dependence engender fear to a degree greater than that associated with domestic acquisition?¹⁰ One possibility is that a foreign supplier might refuse to supply some critical component to the United States during a future war, thus impairing U.S. war-fighting capability. An important variation of that case is the possibility that foreign supplies—or foreign insurance—might become unavailable during a future contingency, perhaps because of threats to sea lines of communication. Another possibility is that a foreign supplier (or host government) might threaten restrictions in sales of defense goods as a means of exerting leverage over some U.S. policy. These fears assume implicitly that the overseas seller enjoys some measure of exclusivity in provision of the needed supplies, and in particular that adequate insurance against such (threatened) cutoffs cannot be provided in advance either domestically or by other foreign producers. If such insurance difficulty is present, then the foreign dependence in such cases indeed may carry greater vulnerability. But it is necessary to specify the reasons that adequate insurance is difficult or impossible to obtain.

Another fear is that a foreign producer of defense technology—or of equipment embodying such technology—might refuse to sell, or might be prevented during a future contingency from selling, to the United

⁹A good example is the recent report of the Defense Science Board, referenced above in footnote 2.

¹⁰If foreign dependence in fact is subject to more or more kinds of disruptions, then acquisition of more insurance might be necessary than would be the case with a greater degree of domestic dependence. But this extra "tax" on foreign acquisition, for the reasons already discussed, might make foreign dependence more costly overall but would not imply greater vulnerability. And if it is domestic dependence that is more difficult to insure adequately, then it is domestic dependence that in fact is the more costly and that therefore ought to engender the greater fear.

States. Alternatively, foreign producers might sell to potential adversaries. This latter possibility is not a dependence or vulnerability or insurance problem *per se*, but instead is a problem in technological competitiveness itself. Insurance must take the form of investments in technological competitiveness, or in substitutes for such prowess. Thus, the private sector responding to perceived incentives from DoD, or the DoD acting directly, could provide such "insurance." Whether incentives to do so are adequate is discussed below.

There is the further problem that the term "foreign" harbors substantial ambiguity. Is a foreign-owned firm whose relevant production facilities are located in the United States "foreign" or "domestic?" What about a U.S.-owned firm operating overseas? And precisely what do we mean by "foreign-owned" or "U.S.-owned" in a world in which capital markets are international, perhaps yielding international ownership? The mere location of corporate headquarters is unlikely to shed great light upon the dependence and vulnerability issue. Instead, analysis is likely to progress more fruitfully if the location issue is used to delineate the sorts of contingencies that are likely to arise *and* the ensuing implications for the availability of adequate insurance. Again, an important case is one in which "foreign" insurance refers not to ownership, but instead to location outside the United States, perhaps raising fears that access to the insurance might be impaired or blocked during a future contingency.

Accordingly, it is useful to recognize that adverse events affecting supply sources of defense goods often can be hypothesized or foreseen as a general proposition, but not predicted in specifics except with great uncertainty. This is true for both domestic and foreign acquisition. Nonetheless, the possibility or probability of adverse events as a generic class can be anticipated, much as individuals prepare for unknown but foreseeable events. Such foresight ought to lead the private sector or the government, or both, to acquire insurance against such contingencies, whether arising out of dependencies that are foreign or domestic. Indeed, even foreigners might perceive an opportunity to provide future insurance for the U.S. defense sector. Two questions arise immediately:

- What factors might hinder the provision of adequate insurance?
- What conditions might reduce or eliminate the adverse effects of those perverse factors?

Since insurance can be provided by the private sector, by the government, or by foreigners, it is useful to address these two questions to each potential insurance source in turn.

THE PRIVATE SECTOR

Let us begin with the private sector. It knows, for any given good valued by the DoD, that supply interruptions may occur or that a loss of technological leadership in a given area might arouse concern on the part of DoD. Such interruptions presumably would raise the price of the goods involved, while the development of technological improvements could prove profitable. Thus, one might expect the profit motive to lead the private sector to invest in insurance against supply interruptions or specific areas of foreign technological dominance.

What is of interest is the very real possibility that, in some instances, the private sector may have disincentives to acquire adequate insurance, thus yielding a true "vulnerability." Such disincentives can stem from several sources, a few of which can be listed as follows:¹¹

- An expectation of price controls.
- Public sector monopsony.
- The corporation income tax.
- Regulatory policy.
- Difficulty in writing or enforcing some kinds of contracts.
- Cost-plus contracting by DoD.
- Poor information about future contingencies.

First, as noted above in the case of crude oil, there is the problem posed by the expectation of price controls. By confiscating part of the future value of private investments in dependence insurance—examples of which are stockpiles, standby production capacity, and substitute goods—an expectation of future controls in effect biases downward private incentives to invest in adequate insurance. The U.S. experience during the Second World War and the Korean conflict was an attempt by the U.S. government to impose price controls on a very broad range of goods, but in stages.¹² The price control program during the 1970s was less extensive (except for short periods) but bore remarkable similarities to the earlier program.¹³ As a crude summary, controls were easiest to impose and enforce upon goods

¹¹This list is not intended to be exhaustive, but instead to provide examples of the sorts of factors that vulnerability analysis must confront. As discussed in the final section, a fuller list is an appropriate topic for future work.

¹²See, for example, John Kenneth Galbraith, *A Theory of Price Control*, Harvard University Press, Cambridge, MA, 1952.

¹³See the *Historical Working Papers of the Economic Stabilization Program*, Cost of Living Council, Washington, D.C., 1974.

with clearly identifiable physical characteristics, that remained homogeneous over time, and the prices of which were relatively easy to define and monitor. Even for such goods, only domestic producers were subject to the controls, for overseas enforcement obviously is difficult, and the supplies made available by foreign producers proved increasingly important as the shortages caused by the controls became manifest. Thus, the controls affected most heavily the markets for commodities and raw materials produced domestically. It is perhaps not surprising, then, that DoD stockpiling in the postwar period has emphasized raw materials and commodities heavily, in part¹⁴ reflecting the disincentives for privately provided insurance emanating from past experience. In short, as DoD surveys its acquisitions and dependencies for lurking vulnerabilities, important goods for which price controls are a realistic expectation during future contingencies constitute an important candidate.

The above discussion of the perverse effects of price controls suggests that inadequate insurance is a real possibility in the case of defense commodities that both are likely to be subject to controls and for which foreign insurance would be problematic in terms of availability after the onset of a future contingency. However, if insurance (i.e., "emergency" supplies) is likely to be available from foreigners and unlikely to be interrupted during a future contingency, then the expectation of price controls would yield inadequate insurance domestically, but not from overseas. In short, a first "rule" for the Department of Defense as it searches for vulnerabilities can be stated as follows: *Domestic dependence for goods likely to be subject to price controls and unlikely to be easily available overseas during a future contingency is an important potential source of vulnerability.*

If the government is the only buyer of a good, or is overwhelmingly the dominant one, Congress may have incentives to reduce the price of the good by reducing the quantity that it purchases. This is known as "monopsonistic" behavior, and is analogous to monopolistic behavior on the part of sellers not constrained by effective

¹⁴The stockpiling program reflects fears as well of the potential unavailability of foreign-produced supplies (insurance) of raw materials and commodities after the onset of future contingencies, that is, expected difficulty in acquisition of needed supplies during future wars or national emergencies. Since the stockpiling is undertaken during peacetime in advance of the potential contingency, it is an important form of insurance. Thus, the foreign dependence *for insurance itself* might carry *vulnerability* nonetheless if access to the foreign insurance during a future contingency is deemed to be problematic. Domestic stockpiling might remove this problem. That the government undertakes the stockpiling suggests the presence of disincentives on the part of the private sector, perhaps the result of expected price controls. Disincentives affecting the behavior of the *government* are discussed below.

competition.¹⁵ If the government can be viewed as operating with the perception of a short time horizon, such behavior yields a perceived gain to the government even as it reduces incentives for the private sector to provide adequate insurance for future contingencies. These reduced incentives result from the lower returns to insurance investment expected as a result of the monopsonistic prices. Such behavior, again, is likely in cases where the government has such monopsonistic power; thus, markets in which the government is not the dominant purchaser are unlikely to provide such disincentives for the provision of adequate insurance. Monopsonistic behavior is more likely in markets for which government purchases are not accompanied by a sizeable commercial market for the same goods. This yields a second "flag" for the likely presence of inadequate insurance provision by the private sector: *Markets in which the government is the sole or dominant buyer and in which reductions in purchases are likely to reduce prices significantly are apt to provide reduced incentives for insurance investment by the private sector.*

The corporation income tax induces those subject to it to use a discount rate higher than that used by other businesses, so that expected after-tax returns are equalized in corporate sectors and other sectors not subject to this tax.¹⁶ This means that before-tax returns—and thus discount rates—are raised in the corporate sector. This has the dual effect of reducing corporate investment overall and of shortening the economic lives of the investments that are made.¹⁷ Investment in dependence insurance in anticipation of a future defense contingency is just such an investment for which the corporation income tax biases private incentives downward, to the extent that the corporate sector would be the more efficient provider of such insurance. The effect is likely to be particularly pronounced for potential contingencies that are relatively distant in time. As in the case of price controls, this provision of inadequate insurance by the private sector can be overcome if insurance can be supplied by foreigners easily even during future contingencies. In short, a third

¹⁵Note that this is a source of inadequate insurance provision by the private sector. Other reasons that the government might have incentives to provide inadequate insurance are discussed below.

¹⁶See Arnold C. Harberger, "The Incidence of the Corporation Income Tax," *Journal of Political Economy*, June 1962.

¹⁷This argument differs greatly from the more common assertion that the U.S. business sector is more concerned with short-term profit than with long-term growth, a view the popularity of which is far greater than the body of supporting evidence. An example is the recent report of the Defense Science Board (footnote 2 above). See also Michael C. Jensen, "Takeovers: Their Causes and Consequences," *Journal of Economic Perspectives*, Winter 1988.

area of concern is created by the effects of the corporation income tax: *True vulnerability may be present in the case of dependencies for which adverse events are distant in time and for which foreign insurance would be difficult to obtain during the future contingency.*

Regulatory policies of various sorts can increase the cost or feasibility of insurance provision by the private sector. Examples are environmental, land use, siting, and contracting restrictions. Moreover, stockpiling is an obvious and commonplace form of insurance, but some types of goods may be difficult to stockpile. Tritium,¹⁸ for example, decays at about 5.5 percent per year. An alternative means of providing insurance in the tritium case is construction of excess capacity in tritium production, probably domestically but perhaps overseas. Regulatory policy affecting the construction and operation of nuclear reactors has a profound effect on the ability of the private sector to provide such insurance. Foreign regulatory policy—not to mention the complexities of international nuclear nonproliferation agreements—may inhibit foreign provision of such insurance.

Similarly, some kinds of insurance contracts might be needed for private sector provision of dependence insurance—for example, such contracts might facilitate private investment by specifying future prices as a function of the age of the investment and other parameters—but such contracts might be quite difficult to write or to enforce. In a fashion similar to that of the regulation case, this difficulty might induce the private sector to eschew the provision of adequate insurance.¹⁹ A third condition yielding such a result is one in which the DoD possesses better information about the likelihood and effects of potential future contingencies, but cannot divulge such information to the private sector, either implicitly or explicitly, perhaps because of security considerations. Again, the private sector would fail to provide adequate insurance against potential contingencies. The problems of

¹⁸The case of tritium is discussed in more detail in Sec. IV.

¹⁹A particularly important case is one in which insurance provision by the private sector requires current investment in assets specialized in the production of the future insurance, in whatever form the latter may take. Once the investment is made, the minimum price necessary to induce future delivery of the insurance is average variable cost, which would exclude the fixed costs imbedded in the investment. Future governments would have incentives to renege on past agreements by lowering the price. But the private sector would recognize this potential problem in advance, and so would have incentives to invest too little in such insurance. See Benjamin Klein, Robert Crawford, and Armen Alchian, "Vertical Integration, Appropriable Rents, and the Competitive Contracting Process," *Journal of Law and Economics*, October 1978. One way to circumvent this problem is through current investment by the private sector combined contractually with current purchase by the government, followed by stockpiling or other insurance provision by the government. Again, this raises the question of the government's incentives in any given case.

regulation, contracting, and information are specialized areas likely to be linked by the absence of a parallel commercial market, as in the monopsony case discussed above. This yields a fourth area of attention for the presence of potential vulnerability: *It may be difficult for the private sector to provide adequate insurance in cases in which the adverse effects of regulations, difficulty in contracting, and asymmetric information are not offset by the presence of a parallel commercial market for the same or substitute goods.*

Finally, a fifth area is cost-plus contracting for insurance—based upon historical or accounting cost instead of market value at the time of purchase—that can provide important disincentives for provision of goods the market values of which tend to rise over time. If values rise but prices do not, then future prices will not cover opportunity (replacement) costs, thus in effect imposing a loss upon suppliers. Such contracting is thus likely to bias private sector incentives downward.

THE GOVERNMENT SECTOR

Since defense can be viewed as a collective good—once produced, it is available both to those paying for it and to “free riders” alike—it ultimately is the government that “provides” (i.e., pays for) insurance for defense-related dependencies. The private sector may be the efficient producer of insurance under some conditions, but ultimately does so only if given the appropriate incentives by the government, because of the collective nature of defense. Under various conditions, some of them discussed above, the incentives and constraints perceived by the private sector fail to induce provision of adequate dependence insurance. It is reasonable, therefore, to ask whether the government is led to provide adequate insurance in cases in which the market fails to do so. What is of more specific interest is the question of conditions under which the government can be predicted to fail to provide adequate insurance, thus yielding a vulnerability. Two general sources of such government “failure” can be delineated as follows:

- Short time horizons for government decisionmakers.
- Government insurance provision of little benefit to private interests, and thus of little political interest.

One of the curious characteristics of the dependence debate has been the emphasis upon the purportedly short time horizon of the

U.S. business sector.²⁰ Whatever the merits of those assertions, there does exist a large body of literature suggesting the presence of incentives inducing public officials and administrators to behave as if discount rates are high,²¹ that is, to use short time horizons. This behavior stems from relatively short tenures in office combined with a perception of small political benefits derived from current actions yielding social benefits in the relatively distant future. Thus, the government may have incentives to underfinance the provision of insurance when the private sector otherwise would have sufficient incentives to produce it, and may produce too little insurance when the private sector provides an inadequate amount. If the source of this inadequacy is the use of a short time horizon, then a sixth area of concern is that in which *the private sector provides too little insurance and the potential adverse events requiring insurance are distant in time, thus reducing the interest of current officials.*

Although defense can be viewed as a collective good, it comprises elements the production of which may benefit private ("special") interests in varying degrees. The traditional argument for public financing of collective goods is predicted underprovision by the private sector; businesses would perceive benefits from the sale of collective goods that are exceeded by the benefit to the economy as a whole. However, it is just as easy to predict that the government will exhibit the same bias against the provision of collective goods, one of which is insurance against defense dependence and vulnerability. Consider a government that provides collective goods that benefit the nation as a whole, an example of which is defense insurance, as well as transfer programs primarily benefiting special interests. By reducing defense spending—or the provision of defense-related dependence insurance—special interests constituting a majority coalition can benefit themselves at the expense of the polity at large,²² by substituting transfers to themselves in place of some dependence insurance of

²⁰See footnote 17.

²¹See, for example, William A. Niskanen, "Bureaucrats and Politicians," *Journal of Law and Economics*, 1975.

²²See, for example, Richard E. Wagner, *The Public Economy*, Markham Publishing Co., Chicago, 1973, pp. 38–52. Military expenditures are not wholly indivisible (or purely collective in nature) because military bases and defense contractors are located in particular geographic areas or congressional districts. Thus, the practice of dispersing bases and contracts among a large number of congressional districts may be a method of increasing the defense budget relative to the nondefense budget, by enhancing the degree to which the benefits of defense spending are divisible. This might achieve greater efficiency in the allocation of resources in the public sector overall. Nonetheless, defense is likely to embody considerably more "publicness" than the non-defense expenditures of government.

interest to all.²³ In short, a seventh source of vulnerability is a *condition under which the private sector provides too little insurance and the public sector perceives few private interest benefits in its provision.*

THE FOREIGN SECTOR

The preceding discussion suggests several reasons that insurance provided domestically may be inadequate, perhaps yielding systematic vulnerability associated with domestic dependence. Foreigners can provide insurance, and may have particularly strong incentives to do so if they perceive inadequate incentives on the part of the U.S. private sector or government. An important problem arises, however, if access to the insurance is perceived to be problematic during a future contingency. If delivery of the insurance is likely to be difficult to protect against interdiction, or if the foreign government might refuse permission for export of the insurance, the insurance is unlikely to be adequate, and producers located overseas are unlikely to perceive adequate incentives to provide it (unless payment for some reason is not made contingent upon delivery). In short, an eighth source of inadequate insurance is *inadequate provision domestically combined with problematic access during contingencies to insurance produced overseas.*

CONCLUSION

The preceding discussion suggests that the following conditions may result in vulnerability defined as inadequate insurance.

²³Note that transfer programs may embody some "collectiveness," particularly if democracies choose to fund them in part because of the indivisible benefits received by taxpayers from the knowledge that others thus are provided access to some minimum level of "necessities." See, for example, Harold M. Hochman and James D. Rodgers, "Pareto Optimal Redistribution," *American Economic Review*, September 1969. Nonetheless, if the collective or indivisible benefits of government redistribution programs were the only or main objectives of such spending, then we would expect the policy to take the form of straightforward pecuniary subsidies for charitable activity chosen by private individuals. Tax deductibility for charitable donations is an obvious form that such subsidization can take. That the government chooses to undertake major redistribution programs oriented toward particular groups of beneficiaries indicates that the private or divisible benefits are the more important motivation. See James D. Rodgers, "Explaining Income Redistribution," and James M. Buchanan, "Who Should Distribute What in a Federal System," in George E. Peterson and Harold M. Hochman (eds.), *Redistribution Through Public Choice*, Columbia University Press, New York, 1974. See also James M. Buchanan, *Public Finance In Democratic Process*, University of North Carolina Press, Chapel Hill, 1967, Chap. 9.

- Important defense goods likely to be subject to price controls and unlikely to be available from overseas during a future emergency.
- Important defense markets in which the government is the sole or dominant purchaser and in which reductions in government purchases are likely to yield reductions in prices.
- Dependencies for which adverse events are distant in time and for which foreign insurance would be difficult to obtain during the contingency.
- Cases in which the adverse insurance effects of regulations, contracting difficulties, or information costs are accompanied by the absence of a parallel commercial market for the same or substitute goods.
- Cost-plus contracting by DoD that may bias incentives downward by posing the prospect of future prices that fail to compensate suppliers for the market value of the insurance sold to DoD.
- The absence of adequate insurance provision by the private sector, combined with potential adverse events requiring insurance but which are distant in time.
- Inadequate insurance provision by the private sector combined with the presence of few important benefits to private interests from governmental provision.
- Inadequate insurance provision domestically combined with problematic access to foreign insurance during future contingencies.

This discussion suggests that it is largely domestic factors that may yield vulnerability. Foreign dependence may contribute to such vulnerability if needed goods cannot be delivered during future contingencies, but the availability of foreign insurance often may offset the adverse effects of domestic constraints. Thus, in an a priori sense, the foreign variable does not seem necessarily to be a systematic source of vulnerability, and ironically may operate in a beneficial fashion. Other important factors are the size of parallel commercial markets, lengthy perceived distance in time of contingencies, and the benefits to private interests from public provision of adequate insurance. Additional insights into these relationships may be derived from examination of some important examples, to which we now turn.

IV. FOUR EXAMPLES: TRITIUM, SAW TECHNOLOGY, DRAM CHIPS, AND HDTV

TRITIUM

Tritium is a crucial component in U.S. nuclear weaponry.²⁴ The inventory is about 50 kilograms, but because tritium decays at a rate of about 5.5 percent per year, it must be produced and replaced over time. U.S. nuclear weaponry could be redesigned to operate without tritium, as may be the case with Soviet nuclear weaponry, but such a change would require additional changes in warheads, delivery systems, and other physical aspects of the U.S. nuclear force structure. An attempt to do without tritium, given the design and configuration of U.S. weapons, therefore would constitute a mammoth and very expensive undertaking.

In short, the U.S. nuclear weapons program requires several kilograms of tritium per year. The United States has depended entirely upon tritium produced domestically at the three Savannah River production reactors, at the Hanford reactor, and at the Rocky Flats facility. All five facilities have been shut down for a number of months because of a series of perceived operational, environmental, and safety problems.²⁵ Thus, tritium is a strategic nuclear material for which U.S. dependence is entirely domestic, but the stockpile of which may be depleted in a matter of months. An attempt to restart production at Savannah River could take more than a year, and the length of time that those facilities could continue production is uncertain. There is virtually no commercial market for tritium, and so there are no commercial supplies that could be allocated for U.S. military use.

A review of options available to deal with the tritium problem suggests that such insurance as exists is far from adequate. In the short term, some options can be summarized as follows:

- Use of some tritium now deployed in existing U.S. nuclear weapons. This may reduce the number and/or the efficiency of weapons available for deterrence or retaliatory strikes.

²⁴The numbers that follow are crude approximations inferred from unclassified sources.

²⁵In addition, the feed materials production center at Fernald, Ohio, which produces certain components for the Savannah River reactors, has been closed since October 1988 because of a labor dispute and environmental concerns.

Since the recycle time for tritium is about five years per weapon, this option is unlikely to be viable for more than a short period.

- Acceptance of reduced performance efficiency—perhaps to a serious degree—for U.S. weapons. The dangers and uncertainties inherent in such a course are great and obviously would grow over time. This option, again, if it is viable at all, could not be sustained for long.
- Purchase of tritium from such foreign producers as France, the United Kingdom, and Canada. This course may prove feasible, but is far from straightforward, as it may carry adverse implications in terms of the nonproliferation treaty, and in any event is likely to pose problems for the supplier governments in terms of both domestic politics and foreign policy. In short, using foreign tritium supplies as insurance is problematic at a minimum.
- Start-up of existing facilities despite safety and other concerns. Apart from safety and other risks—and attendant political costs—a serious adverse event might force a shut-down of domestic tritium production for a period even longer than otherwise would be the case. Thus, again, this course viewed as insurance carries considerable problems and risks.

In the longer term, some options include:

- Conversion of commercial reactors for tritium production.
- Upgrading of existing production facilities.
- Construction of new or new kinds of production facilities.
- Redesign of U.S. nuclear weapons and associate equipment, facilities, and delivery systems.

For purposes of this discussion of dependence insurance, it is unnecessary to delve into detail about these options other than to note the great cost and long periods of time likely to be required for each. In terms of the dependence insurance and vulnerability parameters discussed in Sec. II, the central features of the U.S. tritium problem can be summarized as follows:

- Tritium is a strategic nuclear material for which dependence is entirely domestic, and for which virtually no commercial market exists.
- The usual association of vulnerability with foreign dependence is inapplicable.

- Regulatory constraints prevent the private sector from investing in such insurance as excess production capacity or stockpiling from foreign production.
- Acquisition of tritium produced overseas as insurance is problematic.
- Government investment in excess production capacity is viewed as expensive and, more to the point, would require lead times of a decade or more. If political decisionmakers indeed have short time horizons, the lead times may provide disincentives for provision of adequate insurance by the government. Indeed, this condition may explain in part the situation as it now presents itself.
- The number of sites providing excess capacity necessarily would be limited sharply (perhaps to only one), and construction of the facilities would be unlikely to benefit private interests in a large number of states and congressional districts. Moreover, nuclear construction of any kind carries substantial political opposition. In short, political incentives are likely to reinforce the short-term time horizon problem already noted.
- Notwithstanding the completely domestic nature of U.S. dependence, the degree of vulnerability clearly is substantial. Indeed, because acquisition of tritium from overseas is an important option for the short term, the factors yielding inadequate domestic insurance despite the complete U.S. dependence ironically may lead to important foreign dependence.

SAW TECHNOLOGY

SAW (surface acoustic wave) technology has been known for many decades, but only since the 1960s has it been applied in electronics. Application of the technology became widespread in the United States, and then primarily in Japan and South Korea, for both commercial and military ends. SAW technology has many military applications in radar, naval communication circuits, and in some types of pressure and temperature sensors.

Transistors and oscillators can be substituted for SAW devices in both commercial and military applications, with efficiency losses ranging from slight to substantial. The advantage of SAW devices stems from the SAW use of acoustic rather than electromagnetic waves to propagate energy. This means that the SAW device can be

reduced in size and weight relative to a conventional electronic component performing a similar function. The military benefit of SAW technology stems from this size and weight reduction; for example, SAW devices used for radar signal processing are smaller, faster, and less expensive than digital substitutes.

Production of SAW devices is not difficult technologically, and in fact is similar to techniques used for such microelectronic circuits as semiconductor integrated circuit chips. Moreover, since production processes for SAW devices are similar to those used in the production of integrated circuits, advances in manufacturing technology applicable to the latter can be employed in the production of SAW devices as well. Despite the fact that Japan and South Korea now are the primary production centers for SAW devices, substantial production continues in the United States; at least 20 percent to 30 percent of SAW devices used in the United States are produced domestically.²⁶ A large domestic production increase would not require a lengthy period for achievement; a year is a common estimate.

In the context of the dependence insurance and vulnerability parameters discussed in Sec. II, the central aspects of U.S. military use of SAW technology can be summarized as follows:

- The growing dependence on foreign producers, particularly in Japan and South Korea, suggests the future feasibility of production in other nations, perhaps also in the Pacific Rim, thus reducing sharply the possibility of attempted leverage. Moreover, this foreign production capacity is an important form of insurance, unless separate factors suggest that access to the foreign supplies would be problematic during a future contingency.
- Substantial U.S. production capacity remains and could be expanded in response to, say, DoD contracts relatively quickly. Thus, time horizon, contracting, and regulatory constraints on domestically produced insurance appear not to be important.
- Even without SAW technology, such substitutes as transistors and computer chips are available, with efficiency losses ranging from minor to large. These substitutes are an important form of insurance.
- A large commercial market exists, reducing the ability of the government to engage in monopsonistic behavior.

²⁶Herbert L. Robinson, "The SAW Market," unpublished market survey, 1987.

- In short, the increasing foreign dependence of the U.S. economy for SAW technology does not imply increased vulnerability. Current incentives for provision of insurance appear adequate. Thus, substantial foreign dependence has not yielded vulnerability as contrasted with the tritium case, in which complete domestic dependence has yielded great vulnerability.

DRAM CHIPS

DRAM (dynamic random access memory) chips provide the working memory in computers or other information processing equipment that require temporary internal storage space for data. This memory allows faster execution in both personal and larger computers. The rapid technological advance of the computer industry has been driven by a combination of faster microprocessors, larger capacity DRAM chips, and more powerful software. DRAMs do not have close substitutes, although advanced software can be used to "shuttle" data and commands back and forth between working memory and permanent storage, thus simulating operations facilitated with larger DRAM capacity but with reduced speed or efficiency.²⁷ Moreover, successive generations of DRAM chips can be used, within some limits, as substitutes for each other. The existing supply of DRAM chips thus may serve as a crude stockpile from which insurance supplies could be obtained, at some cost and at some loss of efficiency.

Military use of DRAM chips is manifested primarily by indirect purchases by DoD contractors and their suppliers. DRAMs are components of such defense goods as communications equipment and weapons, but the larger share of ultimate DoD demand is represented by intermediate use in computers and other products used to produce the defense goods. The share of DRAM chips used directly or indirectly in defense activity is estimated in an input/output format at about 5 percent.²⁸ Thus, DRAM use is overwhelmingly commercial.

Some characteristics of DRAM chip production are of interest. Fixed costs are high relative to marginal (or variable) costs, yielding important scale economies in production, which appear to be increasing with

²⁷However, it may be the case that more powerful software is less useful as a substitute for DRAM chips in such defense-related computer applications as computer assisted design/computer assisted manufacturing (CAD/CAM).

²⁸David Henry and Richard Oliver, "The Defense Buildup, 1977-1985: Effects on Production and Employment," *Monthly Labor Review*, August 1987.

successive generations of DRAM chips. Moreover, marginal cost appears to shift downward with cumulative production, due perhaps to a "learning" phenomenon. The trend is reflected by increasing percentages over time of chips not rejected for defects, which may range from less than 50 percent initially to over 90 percent after a period of some months or years. The upshot of this, combined with technical advance in production and in the chips themselves, is a pattern of declining prices for each generation of chips. For example, prices for 16K chips were about \$46 in 1976, \$18 in 1977, and \$8 in 1978, declining to less than \$1 in 1984. Similar declining patterns have characterized prices for other generations of chips.²⁹ Moreover, prices per bit have declined markedly over succeeding generations of chips. In 1978, prices were about 50 cents per bit for 4K and 16K chips; in 1989, prices ranged from 1 cent to less than 5 cents per bit for 64K, 256K, and 1 megabyte chips. The technical advance reflected by succeeding generations of chips means that each generation tends to become obsolete over time.

The number of U.S. producers has declined sharply. Apart from IBM, there were in 1980 some 11 U.S. firms producing DRAM chips; by 1989, that figure had declined to about three. The U.S. share of the commercial DRAM chip market has declined during this period from about 50 percent to about 20 percent.³⁰ Again, these figures exclude the large production volume by IBM, used almost entirely in its own products. Moreover, the distinction between "foreign" and "domestic" production has become less clear as foreign investment in U.S. producers has become more important, as have licensing and co-production arrangements. For example, Motorola trades microprocessor technology with Toshiba in exchange for DRAM technology. Texas Instruments produces most of its DRAM chips in Japan. Sanyo has entered into an agreement with Mos of Canada to develop and produce 4M DRAM chips.³¹

From the viewpoint of the market, stockpiling and excess production capacity for DRAMs as forms of insurance are costly. As noted above, prices for given generations of chips tend to fall over time, as do prices per bit across generations. Thus, a stockpile of DRAM chips would represent an asset with declining value. This means that stockpiling of chips is costly, particularly if future DoD needs during

²⁹Richard E. Baldwin and Paul R. Krugman, "Market Access and International Competition: A Simulation Study of 16K Random Access Memories," in Robert C. Feenstra (ed.), *Empirical Methods for International Trade*, MIT Press, Cambridge, Massachusetts, 1988.

³⁰See *Los Angeles Times*, June 22, 1989.

³¹See *Electronics Purchasing*, February 1988; and *Japan Economic Journal*, May 6, 1989.

contingencies are apt to arise at a time that currently stockpiled chips already will have become obsolete.³² Moreover, even if the chips serving as insurance are useful for DoD purposes, they will have to compete in the insurance market with the inventory already installed in existing equipment. Insurance in the form of excess production capacity is costly as well. Efficient production scales are large, so that idle facilities would be expensive to construct. Moreover, since prices for the chips decline over time, the value of the excess production capacity, for any given set of contingency expectations, declines as well; as with the chips themselves, a "stockpile" of production capacity is costly to maintain. And the "learning curve" phenomenon may add to future costs: initial production from surplus capacity at the time of the contingency may yield relatively low yields of chips without defects.

These factors indicate that the market will invest in only small amounts of such insurance.³³ Since DoD as a user of DRAM chips is small relative to the market, the presence of the much larger market may provide an adequate amount of insurance, as a surge in DoD purchases during a future contingency might not affect the market greatly. However, to the extent that the larger market serves as insurance for DoD, but is located overseas, any perceived difficulty in transport or acquisition of foreign chips during a future contingency reduces the value to DoD of the overall market as insurance.

Other factors may distort the amount of insurance provided by the market downward even more. Once the DRAM chips (or excess capacity) are produced, much of the future price promised for the insurance would be sunk or imbedded as fixed costs in fixed facilities, providing the government with a perceived incentive to renege on the agreement.³⁴ Moreover, that much of the military demand for DRAM chips is indirect suggests the possibility that it may be difficult for DoD to convey information about its future willingness to pay for current investment in insurance. Finally, some regulatory policies, such as wrongful termination policy, may be particularly important to the semiconductor industry and others subject to major cyclical swings in demand conditions. Such policies may combine with the cyclical nature of the industry to yield less investment than otherwise would be the case, and thus result in inadequate provision of

³²It is interest rates and the expected price paid by DoD at the time of the contingency that determine market incentives to provide insurance.

³³The small amount of explicit insurance provided by the market may not be distorted downward, but may be inadequate from the viewpoint of DoD if its aversion to a future risk of a DRAM chip contingency is sufficiently high.

³⁴See footnote 19.

insurance by the private sector. Export restrictions may reinforce this problem.

Some factors may offset these potential problems. Ironically, cost-plus contracting for stockpiles or excess capacity may enhance incentives for stockpiling precisely because of the declining asset values. Cost-plus computation of future prices may promise future prices higher than prevailing market value. The 1986 Semiconductor Trade Agreement, by cartelizing the industry and raising prices sharply, provides incentives for investment in production capacity; at least some of this investment may take the form of excess capacity, unless legal restrictions constrain such "entry" by members or nonmembers of the cartel. Thus, if the DRAM market has been characterized by inadequate insurance, the 1986 Agreement may offset that effect. Whether cartelization of the industry is the efficient method with which to achieve such a result is an issue lying beyond the scope of this report.³⁵

With respect to the dependence and vulnerability issue, the central aspects of the U.S. DRAM chip market can be summarized as follows:

- Foreign dependence in the DRAM market is growing, but that trend by itself does not suggest growing vulnerability unless the foreign production is unlikely to be obtainable during a future contingency. Although substantial domestic production remains—including that by IBM, representing about half of U.S. output—existing DRAM chips and advanced software can serve as imperfect substitutes only at some cost and loss of efficiency. Unlike the SAW technology case, close substitutes are not available; moreover, a substantial expansion of production capacity would be likely to consume years rather than months.
- Even in the absence of distorted incentives, private sector investment in insurance is likely to be small because of declining asset values for stockpiles of chips and for excess production capacity. This small level of insurance may be "adequate" in the sense of economic optimality given the costs of providing insurance, but may be too small from the defense

³⁵See Earl Thompson, "Taxation and National Defense," *Journal of Political Economy*, 1974; and Earl Thompson, "An Economic Basis for the 'National Security' Argument for Protecting Certain Industries," *Journal of Political Economy*, 1979. An example of the perversities inherent in cartelization is provided by the indirect effects of the 1986 Agreement. By making DRAM chips more expensive, investment in sectors that use the chips—many of which are defense-related—is likely to fall, thus perhaps reducing dependence insurance in those industries to inadequate levels.

standpoint if DoD is substantially more averse to risk than is the private sector in this market.

- Contracting, contract enforcement, information, and some regulatory policies may serve to bias investment incentives downward for the private sector even more. However, the 1986 Semiconductor Trade Agreement, along with any expectation of cost-plus bases for payment, may offset those effects.
- Incentives for provision of insurance appear less adequate than in the SAW technology case, particularly if DoD aversion to future risks is important. This conclusion is driven by the absence of close substitutes and by factors leading the private sector to provide low levels of insurance, whether "optimal" or not. If future transport of foreign DRAM chip insurance during contingencies is problematic, then the increasing foreign dependence may carry greater vulnerability.

HDTV

High-definition television (HDTV) is a range of emerging technologies producing a television picture with improved clarity on screens larger than currently in widespread use. In particular, picture resolution would be improved on the larger screens, thus arousing interest in HDTV among military planners.³⁶ HDTV development at this time is largely confined to Japanese firms.

Let us assume that the military potential offered by HDTV is substantial. Prospects for development of a large commercial market for HDTV are problematic at best; thus, DoD is unlikely to be able to derive military use as an ancillary benefit of commercial growth.³⁷ Unless the Japanese HDTV industry receives subsidies from the Japanese government on a continuing and long-term basis, the

³⁶An additional argument often made is that development of HDTV will "drive" the development of other technologies, thus improving the competitiveness of the U.S. electronics sector and providing additional military benefits. This argument seems questionable. The memory chips used in HDTV are used widely in computers and other products, and even the display and imaging technology is under continuing development by the U.S. computer industry. Moreover, the Congressional Budget Office notes that the likely size of the commercial market for HDTV is sufficiently small as to cast doubt on the future role of HDTV as a catalyst for widespread development of new technology in the electronics sector.

³⁷See "The Scope of the High-Definition Television Market and Its Implications for Competitiveness," Congressional Budget Office staff working paper, July 1989. See also Thomas Gale Moore, *The Promise of High-Definition Television: The Hype and the Reality*, Cato Institute for Policy Analysis, No. 123, August 30, 1989. The reasons for this include expected high cost and only marginal improvement in picture resolution in many commercial applications.

existence of a large foreign commercial market cannot be assumed to provide adequate insurance for future U.S. defense needs, even if access to foreign (Japanese) HDTV during future contingencies poses few expected problems. One point to be noted is that assembly of HDTV is likely to be performed in the U.S. even if HDTV components are produced overseas, because of the damage potential inherent in lengthy transport of large television sets. This factor explains why over two-thirds of all color television sets—and virtually all large-screen television sets—sold in the United States are assembled domestically.

Conventional electronic components are good substitutes for HDTV, and the United States produces about 20 percent of all conventional components used. Still, under the assumption that conventional components are not good substitutes for HDTV in military applications, the prospects for domestic development of adequate insurance hinge on whether the private sector perceives adequate incentives. Price controls for heterogeneous and evolving goods do not seem probable, but since the government is likely to be the dominant buyer, potential monopsony disincentives may be important from the viewpoint of the private sector. This condition may also affect perceptions of the future ability of the private sector to recover its costs imbedded in HDTV capacity created for insurance purposes. Moreover, such investments are likely to be long term, perhaps reducing further the willingness of the private sector to provide adequate insurance.

In short, the private sector seems unlikely to provide adequate insurance for military use of HDTV. Direct governmental provision of such insurance may be appropriate. Unlike facilities producing tritium, HDTV facilities are unlikely to require long lead times, and would produce goods yielding military services immediately and on a continuing basis. Whether a large number of private interests would be involved is less clear, but there is no a priori reason to conclude that future political processes will result systematically in provision of too little insurance.

The central dependence and vulnerability points for HDTV can be summarized as follows:

- Development of a substantial commercial market for HDTV is problematic at best.
- Conventional electronic components are good substitutes for HDTV in commercial uses but may be poorer substitutes in military applications.

- If dependence develops, it is likely to be foreign for components but domestic for assembly. The foreign production of components may be uncertain if it depends upon subsidies provided by foreign governments, and this foreign insurance, even if forthcoming, may not be adequate if access to the components is uncertain during future contingencies.
- Provision of insurance by the private sector is likely to be hindered by the expectation of public sector monopsony and by the presence of sunk and fixed costs in prices covering full costs.
- The private sector, therefore, will probably not provide adequate insurance for future DoD HDTV requirements.
- This suggests that governmental provision of insurance may be appropriate. One form of such insurance may be contracts to develop and produce HDTV components specifically designed for military use and not otherwise available.

V. CONCLUSIONS

Table 1 summarizes the vulnerability factors for the four examples discussed in Sec. IV. The examples vary in several important dimensions, making the comparisons interesting despite the small sample size. Dependence in the tritium case is entirely domestic, whereas it is both foreign and domestic in the SAW technology and DRAM chip cases. For HDTV, dependence is likely to be foreign, although assembly will be substantially domestic. For SAW technology, the growing foreign dependence does not suggest vulnerability; there is a large commercial market and many good substitutes, and the disincentives that otherwise might yield inadequate insurance are not important. Few close substitutes are available for DRAM chips, and despite the presence of a large commercial market, the amount of insurance likely to be provided by the private sector is small. This suggests a potential vulnerability problem, particularly if access to foreign insurance during a future contingency is problematic and if DoD is more averse to risk in this market than is the private sector. For HDTV, substitutes are available, but development of a large commercial market is not a strong prospect either domestically or overseas. There may be important disincentives for the provision of adequate insurance, such as potential monopsonistic behavior by the government.

The discussion suggests that foreign dependence by itself does not yield vulnerability, and in fact may offset vulnerability caused by domestic conditions. Moreover, U.S. location of foreign facilities offsets any vulnerability caused by foreign location, which may raise access problems during future contingencies. Our examination of the four examples is consistent with those inferences. The foreign variable, by itself, is not particularly important, except to the extent that foreign location of insurance implies access problems during future periods in which the insurance is needed. Instead, the important sources of vulnerability seem to be the absence of a large commercial market or of substitutes for the technology in question, combined with other factors that lead to inadequate provision of insurance by the private, government, or foreign sectors.

This suggests that the Department of Defense, as it surveys its myriad dependencies, would do well to avoid the usual concentration upon foreign sources of technology. Instead, the factors discussed in this report should serve as warning signs deserving of detailed

Table 1
DEPENDENCE AND VULNERABILITY FACTORS

Factor	Tritium	SAW Technology	DRAM Chips	HDTV
Dependence	Domestic	Foreign/ domestic	Foreign/ domestic	Foreign
Location	Domestic	Foreign/ domestic	Foreign/ domestic	Foreign/ domestic
Commercial Substitutes	None	Large Good	Large Poor/ moderate	Small? Moderate/ good
Price control risk				
Regulation problems	High	Low	Medium	Low
Monopsony risk	n.a./high	Low	Low	High?
Foreign insurance	Problematic	High	Medium/high	Low?
Access to foreign insurance	High?	Medium?	Medium?	Medium?
Time horizon	Long	Short?	Short?	Medium
Lead time	Long	Short	Medium	Medium
Private interests	Few	Many?	Many?	Many?
Vulnerability	High	Low	Low/medium	Medium

scrutiny and allocation of limited DoD resources. The discussion in this report also suggests that with the exception of contract provisions, the sources of inadequate insurance largely lie outside the control of DoD. This is particularly true for expectations of price controls, monopsonistic behavior, short governmental time horizons, and other political factors. DoD efforts to defend sea lanes and other important aspects of access to foreign insurance during periods of future need are emphasized.

Further work on critical dependencies of the DoD is required. First, more detailed and finely defined sources of vulnerability are a *crucial need*. Second, better definition and measurement of insurance are called for. And third, application of an improved and expanded analytic framework to a greatly enlarged sample of DoD dependencies would be a logical and important following step.

However, there are a few preliminary policy implications. Many of the disincentives perceived by the private sector *can be rectified only* by Congress, and even in those cases the viability of such reforms over time is unclear. An example would be a commitment to eschew the imposition of price controls on likely candidates. Another is the likely preference on the part of the government for special interest spending as opposed to general interest programs providing collective benefits. There are, however, actions DoD can take to improve private sector incentives. Contracts can be written in ways that reduce the future ability of the government to capture the fixed costs imbedded in past investments made by the private sector. One possible way to do that is through concurrent production of insurance by contract, combined with current purchase and future stockpiling by DoD. Another might be through actual provision of excess capacity by DoD. Cost-plus contracting in most cases is likely to provide incentives for inadequate provision of insurance, and further work on alternatives for DoD is important. Thus, a fourth area for further research would be on alternative policy tools that could be used to offset the adverse incentives discussed here. Such an expanded analytic agenda would go far to help the Department of Defense overcome vulnerabilities inherent in its complex and worldwide operations. What is clear is the misleading nature of the standard emphasis upon foreign dependence rather than the sources of inadequate insurance.