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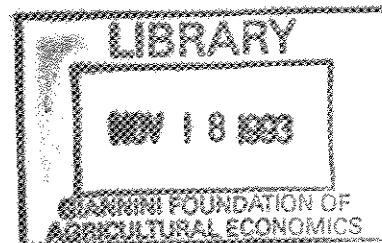
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**WHY INDUSTRIAL POLICIES FAIL:
LIMITED COMMITMENT**

by

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Why Industrial Policies Fail: Limited Commitment

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Abstract

The strategic effects of subsidies on output and subsidies on investment differ substantially in dynamic models where a government's commitment ability is limited. Output subsidies remain effective even as the period of commitment vanishes, but investment subsidies may become completely ineffective. This difference has been obscured because most existing models of strategic trade policy are static.

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Why Industrial Policies Fail: Limited Commitment

I. Introduction

Many economists, political scientists, newspaper columnists, and politicians argue that the United States should imitate its major trading partners and adopt industrial policies to help domestic firms gain a strategic advantage in international trade (increase their "competitiveness").¹ Trade theorists use static or two-period models of imperfect competition to show that taxes or subsidies on output or exports ("output policies") or taxes or subsidies on investment or adjustment ("investment" or "industrial policies") enable a domestic firm to behave as if it were a Stackelberg leader.² The static nature of these models obscures an important difference between output and investment policies. For example, in Brander and Spencer's (1983) two-period model, it appears that output and investment (R&D) policies have similar strategic value. We show that, in a multiperiod model, *investment policies* may be ineffective in shifting rents from foreign rivals to domestic firms whereas *output policies* remain effective.

¹ For example, Borrus, Tyson, and Zysman (1986) argue that the Japanese semiconductor industry became a major competitor on world markets "largely at the expense of the U.S. industry," as "a planned result of a concerted policy effort." Johnson (1984) contends that the Reagan administration, which established a Commission on Industrial Competitiveness, tried to use the Department of Defense to implement industrial policies. See, however, Krugman (1984) for systematic empirical evidence on the practicality of such policies.

² See Spencer and Brander (1983), Dixit (1984), Brander and Spencer (1985), Eaton and Grossman (1986), Gruenspecht (1988), Markusen and Venables (1988), Cheng (1988), de Meza (1989), Neary (1991) and Krishna and Thursby (1991) for conditions under which these results hold.

Although output policies can be used strategically in a dynamic world, their practical importance is limited by their political cost. Export subsidies, with few exceptions such as agricultural products, contravene the General Agreement on Tariffs and Trade (GATT). Moreover, export subsidies are counterproductive if trading partners retaliate. Not only do such output and export policies foster international discord, but the transfers they require carry high domestic political costs. These considerations lead many politicians to prefer industrial policies.³ Such programs, which do not explicitly violate GATT agreements, are aimed at altering the industrial infrastructure, which includes the capital stock, the quality of labor, and institutions that affect the labor market.

In our model, the government sets policies in each period, and then firms make their decisions about investment and output for that period. The government is able to commit for a period. Within each period, the government has a first-mover advantage, but it is unable to make commitments about how it will behave in the future. The government's *limited* ability to make commitments is what distinguishes our model from existing static models.⁴

³ Many countries provide trade adjustment assistance (e. g., the 1974 U. S. Trade Adjustment Act), tax credits for investments, aid to specific industries such as the textile and shipbuilding industries, and various manpower training programs (Frank 1977). Most major developed exporting countries, except the United States, require that firms notify their workers in advance of plant closures (Frank 1977), raising adjustment costs to firms. Magaziner and Reich (1982) also describe other industrial policies including interest subsidies, accelerated depreciation on investments abroad, tax deferral on investments, and marketing assistance (information and promotion and incentives for small businesses).

⁴ The earlier static models cannot be used to examine the issue of credible commitments by governments, as Eaton and Grossman (1988, p. 607) point out. Cheng (1987) uses a dynamic version of the Brander and Spencer (1985) model but considers only open-loop policies, and thus ignores the commitment problem.

Previous papers, including Staiger and Tabellini (1987), Matsuyama (1990), Brainard (1990) and Tornell (1991), have used dynamic models to demonstrate that the first best trade policy is likely to be dynamically inconsistent. This implies that the inability to commit reduces the efficacy of trade policy. Our results extend this conclusion in two ways. First, we show that the inability to commit has a qualitatively different effect for output and investment policies. A limited ability to commit is irrelevant for output policies, but is extremely important for investment policies. Second, we show that in the limiting case, where the period of commitment approaches zero, investment policies become completely ineffective (whereas the efficacy of output policies is not altered). This limiting result provides a lower bound to the value of intervention even when the government's ability to commit is finite though small.

We are not interested in showing, in yet another context, that the set of equilibria of dynamic (or repeated) games can differ from that of static games. Instead, we want to show that the intrinsic properties of output and investment policies are quite different, and that this difference has been overlooked. Toward this end, we take the "standard" static model and make it dynamic. In particular, we adopt the same assumptions about timing of agents' moves and the same equilibrium concept as is used commonly in the standard models.

Previous models of strategic trade use subgame perfect equilibria, which, for finite horizons, are obtained by working backwards from the last period. Agents' decisions are conditioned on payoff-relevant information: the "state." Agents understand how their current behavior will affect agents in the future. We adopt the same equilibrium concept by using a Markov Perfect Equilibrium (MPE). Given the Markov

assumption, punishment strategies, which can support a wide variety of outcomes, are eliminated. The Markov assumption enables us to compare our results with those obtained from previous static models.

The conclusions about output policies based on static models do not change for a dynamic model because the current output decisions do not depend on future policies. The efficacy of industrial policies is dramatically different, however, in a dynamic model than in a static model, because the investment decision depends on future as well as current government policies. Even if the government chooses its industrial policy in the current period before firms choose their investments, the government's next period actions follow those investment decisions. If there are several periods, one agent moves before another in only a limited sense. The static model is a true "first-mover game;" whereas, in the dynamic model, agents alternate moves.⁵

In the next section, we describe the model and explain why output policies are effective in a dynamic setting where the government has a limited ability to commit. In the third section, we explain why industrial policies may become ineffective. Numerical examples are presented in the following section. We summarize and draw conclusions in the last section.

⁵ Maskin and Tirole (1988) and Eaton and Engers (1990) characterize MPE in games with alternating moves.

II. The Model

To illustrate why the two types of policies differ in multiperiod markets, we use a model in which the dynamics stem from adjustment costs.⁶ We assume that there are only two firms — a home firm, h , and a foreign firm, f — that export all their output to a world market. Each firm plays Nash, taking its rival's exports in the current period, t , as given, and chooses its current rate of output, q_i^t , and its current rate of investment, I_i^t , $i = h, f$. The government of the home firm intervenes before the firms act. The foreign government is passive and does not retaliate. In static models these assumptions imply a role for government intervention. Each firm's objective is to maximize the present discounted value of the stream of (subsidy inclusive) profits net of adjustment costs; the home government's objective is to maximize the home firm's profits, net of subsidies and adjustment costs.

Each period lasts for ϵ units of time. For simplicity, we assume that the interval at which decisions are made equals the length of a period of commitment. At the beginning of each period (before firms make their current decisions), the home government chooses an export subsidy, s , and an industrial policy, v . Outside the steady state, policies change over time, but we omit time subscripts where the meaning is clear.

⁶ There is a growing theoretical literature on imperfect competition in the presence of adjustment costs, such as Fershtman and Kamien (1987), Reynolds (1987), Driskell and McCafferty (1989a). Further, many authors show that adjustment costs are empirically important, such as Pindyck and Rotemberg (1983), Epstein and Denny (1983), Epstein and Yatchew (1985), and Karp and Perloff (1989, 1993). Adjustment costs may be either internal to the firm (as is the case when there are bottlenecks, so that rapid adjustment increases average costs of adjustment) or external (as is the case when increased investment increases the costs of investment inputs, or increased disinvestment decreases the second price of second hand machinery).

The level of (human or physical) capital in Firm i at time t is k_i^t , which is given by

$$k_i^t = k_i^{t-\varepsilon} + l_i^{t-\varepsilon} \varepsilon. \quad (1)$$

The vector of capital stocks is $\mathbf{k} = (k_f, k_h)$.

Later we will specialize the model to examine the case where the government can only use investment policies. We start, however, by describing the model in which the government is able to choose both an output subsidy and an investment subsidy at the beginning of each period. This more complex model, which is used to explain why *output* policies remain effective regardless of the period of commitment (ε), is essential to establish the comparison between output and investment policies. Because it is easy to show that the efficacy of output policies does not depend on ε , we merely outline the argument here.⁷

In a Markov equilibrium, for any decision rules that determine the choices of v and l_i , the equilibrium choices of q_i and s are determined in each period by solving a static game. In this static game firms take s as given and choose output to maximize current period profits. A deviation from the equilibrium output level by either firm would not affect the future stock of capital (the state variable). The deviation would consequently not alter future decisions by firms or the government and, hence, would not alter future profits. The government chooses the current output subsidy to maximize the domestic firm's current profits net of the subsidy. In each period the government chooses the subsidy that induces the domestic firms to choose the level of output that would result if that firm were a Stackelberg leader.

⁷ A formal analysis is contained in an earlier working paper, available from the authors upon request.

By solving the static game in each period, we can replace $\mathbf{q} = (q_h, q_f)$ and s by the equilibrium functions $\mathbf{q}^*(\mathbf{k})$ and $s^*(\mathbf{k})$. If this repeated static game is stationary (only the level of \mathbf{k} changes over time) the functions $\mathbf{q}^*(\mathbf{k})$ and $s^*(\mathbf{k})$ are also stationary. Thus, the firms' profit functions can be written in reduced-form as $\pi_i(\mathbf{k})$.⁸ These profit functions are flows (as are output and investment), so the single-period profit of Firm i is $\pi_i(\mathbf{k})\varepsilon$. The government's equilibrium payoff in a period is domestic firm profits net of the transfer: $W(\mathbf{k})\varepsilon \equiv (\pi_h(\mathbf{k}) - s^*(\mathbf{k})q_h^*(\mathbf{k}))\varepsilon$. Because the only effect of ε is to scale the single period payoffs, the magnitude of ε does not alter the efficacy of the output subsidy.

To complete the model, we define each firm's cost (a flow) of investment as $c(I_i, v_i)$, where $v_h \equiv v$ (the home government's industrial policy) and $v_f \equiv 0$ (because the foreign government does not intervene). The *social* cost (i. e., ignoring the transfer) of home investment is, consequently, $c(I_h, 0)$. An industrial policy drives a wedge between the social adjustment cost and the private cost borne by the home firm.

We can think of the policy v as simply a parameter that alters the home firm's adjustment costs. We define v so that a positive value represents a subsidy; that is, $\partial c / \partial I$ is decreasing in v . The function $c(I_i, v_i)$ is strictly convex in I_i so that firms take more than one period to adjust to a long-run equilibrium. If adjustment were instantaneous, there would be no technological source of dynamics.

⁸ If, instead, we write equation (1) as a backward difference equation, so that investment during the current period contributes to the capital stock available in the current period, the game does not have this recursive structure, and the notation is slightly more cumbersome, but the qualitative conclusions remain the same.

The government's objective at time t is to maximize the present discounted value of the stream of social welfare until the horizon, τ :

$$\sum_{n=t}^{\tau} \beta^n (W(k^n) - c(l_h^n, 0)) \varepsilon, \quad (2)$$

where β is the discount factor. The objective of Firm i ($i = h, f$) is to maximize the present discounted value of the stream of profits over the same horizon:

$$\sum_{n=t}^{\tau} \beta^n (\pi_i(k^n) - c(l_i^n, v_i) \varepsilon). \quad (3)$$

III. The Ineffectiveness of Industrial Policies

We now show that, in a MPE to the discrete stage dynamic game, the government's ability to influence the foreign firm by using industrial policies is proportional to ε , which is the length of each stage of the game and the period of commitment. That is, the government's first-mover advantage falls as ε shrinks. In the limiting case, as ε approaches 0, the game becomes a continuous time (differential) game. There is a MPE to the continuous time game in which the government cannot intervene effectively. Next, by placing more structure on the game, we find conditions under which nonintervention is the limit of the sequence of Markov equilibria obtained by shrinking ε .

In order to concentrate on investment, we now assume that the government cannot use output policies, so that $s(k) = 0$ and government welfare in a period (exclusive of investment costs) equals the domestic firm's profits: $W(k) = \pi_h(k)$. Given this assumption, it is unnecessary to specify the type of game the firms play within a period (price or quantity setting). Recall that $\pi_i(k)$ is the reduced form profit function for firm i within a period. The level of k affects a firm's capacity and/or its marginal

cost. The level therefore affects the firm's equilibrium choice of some other variable (e.g. price or quantity) and thus determines its profits. We conclude this section by returning to the more general case where the home government can use both output and industrial policies.

Under the assumption that a Markov equilibrium exists for all ε , we can write the dynamic programming equations for the agents as:

$$J_g(k^t) = \max_v \{(\pi_h(k^t) - c(l_h^t, 0))\varepsilon + \beta J_g(k^{t+\varepsilon})\}, \quad (4a)$$

$$J_h(k^t, v^t) = \max_{l_h} \{(\pi_h(k^t) - c(l_h^t, v))\varepsilon + \beta J_h(k^{t+\varepsilon}, v(k^{t+\varepsilon}))\}, \quad (4b)$$

$$J_f(k^t, v^t) = \max_{l_f} \{(\pi_f(k^t) - c(l_f^t, 0))\varepsilon + \beta J_f(k^{t+\varepsilon}, v(k^{t+\varepsilon}))\}, \quad (4c)$$

The term in square brackets on the right side of each equation is the payoff (profits minus adjustment costs) in the current period (a flow times ε); the second term is the discounted stream of payoffs beginning at the next period. The function $J_i(\cdot)$, $i = g, h, f$, gives the value of the game to agent i . Although each of these functions depends on ε , for notational simplicity, we suppress that dependence. In (4) we assume that the equilibrium is stationary.

Firm i chooses l_i and takes v and l_j ($j \neq i$) in the current period as given. Each firm knows how future values of v will be chosen, so $v^{t+\varepsilon}$ is given by some function $v(k^{t+\varepsilon})$, which is endogenous to the game. Firms have rational point expectations, so they are able to predict future values of the government policy.

Firms maximize their payoffs subject to (1). The first-order conditions, which are assumed to be sufficient for a maximum,⁹ to the firms' problems are

$$\left[\frac{-\partial C(l_i, v_i)}{\partial l_i} + \beta \frac{\partial J_i^*(k^{t+\epsilon})}{\partial k_i} \right] \epsilon = 0, \quad (5)$$

for $i = h$ or f , $v_f = 0$, $v_h = v$, and where we define $J_i(k^{t+\epsilon}, v(k^{t+\epsilon})) \equiv J_i^*(k^{t+\epsilon})$ (so that the second partial derivative includes both the direct effect of k on J_i and the indirect effect, via v). Equation (5) states that the marginal adjustment cost equals the shadow value of capital for each firm in equilibrium. If the system of first-order conditions is invertible, the firms' decision rules can be written as

$$I^t = I^*(k^t, v^t; \epsilon). \quad (6)$$

By totally differentiating the first-order conditions (5) and applying Cramer's rule, we obtain

$$\frac{\partial I_h^*}{\partial v} = \frac{H_{22} \frac{\partial^2 C(l_h, v)}{\partial l_h \partial v}}{|H|}, \quad (7a)$$

$$\frac{\partial I_f^*}{\partial v} = \frac{-H_{21} \frac{\partial^2 C(l_f, v)}{\partial l_f \partial v}}{|H|}, \quad (7b)$$

where H ,

⁹ The analysis of this section relies principally on the first-order conditions of the agents' problems. Numerical experiments show that sometimes the necessary conditions are not sufficient even in the well-behaved linear-quadratic structure (defined below). Thus, it is unlikely that there are any simple conditions on the exogenous functions π and c that insure that the first-order conditions are also sufficient.

$$\begin{pmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{pmatrix} = \begin{pmatrix} \frac{-\partial^2 c(l_h, v)}{\partial l^2} + \beta \frac{\partial^2 J_h^*}{\partial k_h^2} \epsilon & \beta \frac{\partial^2 J_h^*}{\partial k_h \partial k_f} \epsilon \\ \beta \frac{\partial^2 J_f^*}{\partial k_f \partial k_h} \epsilon & \frac{-\partial^2 c(l_f, 0)}{\partial l^2} + \beta \frac{\partial^2 J_f^*}{\partial k_f^2} \epsilon \end{pmatrix},$$

is the Jacobian of the first-order conditions and $|H|$ is the determinant. By differentiating the foreign firm's first-order condition holding v constant, we obtain the slope of its best-response function:

$$\frac{dl_f^*}{dl_h} = -\frac{H_{21}}{H_{22}}. \quad (7c)$$

The government solves the problem in (4a) subject to (1) and (6). The government's first-order condition is

$$\left[\frac{-\partial c(l_h, 0)}{\partial l_h} + \beta \frac{\partial J_g(k^{t+\epsilon})}{\partial k_h} \right] \frac{\partial l_h}{\partial v} + \beta \frac{\partial J_g(k^{t+\epsilon})}{\partial k_f} \frac{\partial l_f}{\partial v} = 0. \quad (8)$$

The partial derivatives of l with respect to v are given by (7a) and (7b). Where there is no ambiguity, we write $\partial l / \partial v$ rather than $\partial l^* / \partial v$.

Given the requirement of perfection and the assumption of stationarity, for all possible values of k^t , the government's optimal choice of v^t is $v(k^t)$. At the beginning of the period, the government is free to choose any value of v^t ; however, due to its inability to commit to future values, the choice it wants to make at t is the same as the expectation of firms in the previous period.

A. Welfare

As a means of demonstrating that our dynamic model is a natural extension of familiar static models, we outline conditions under which the welfare properties of the two types of models are the same. (These conditions hold for the examples we describe in Section IV, but our basic point can be made more simply using only the first-order conditions to the general problem.) We show that a small subsidy increases welfare in the dynamic model, just as in the static analogue, when the two models have similar characteristics. First, we assume that a change in I_i has a greater effect on firm i 's payoff than it does on j 's, so that $|H| > 0$. This inequality and the second-order condition to Firm f 's problem implies $\partial I_h / \partial v > 0$. We also assume that an increase in k_h decreases the foreign firm's shadow value of (its own) capital, which implies that $\partial I_f / \partial v < 0$.

Two additional plausible assumptions allow us to determine the welfare effects of a small subsidy. The first of these is that an increase in foreign capital decreases the value of the government's program: $\partial J_g / \partial k_f < 0$. The second is that the shadow value of k_h is no less for the government than for the home firm: $\partial (J_g - J_h^*) / \partial k_h \geq 0$.¹⁰ If, for example, the government will refrain from intervening in the future or if the current period is the last period (as in static models), this last relation holds with equality.

¹⁰ The government realizes that the anticipation by the rival of an additional unit of home investment in this period decreases the rival's current investment. The home firm, on the other hand, takes the rival's current investment as given. Therefore the government has an additional incentive beyond that of the home firm to increase home investment. As a result, we would expect the shadow value of home investment for the government to be larger than for the firm.

We now determine the welfare effects of a small subsidy. First, with respect to v , we subtract the home firm's first-order condition (5), which holds for all values of v , from the derivative of the government's payoff (4a). Evaluating this difference at $v = 0$, we obtain

$$\left\{ \beta \left(\frac{\partial (J_g(\mathbf{k}^{t+\epsilon}) - J_h^*(\mathbf{k}^{t+\epsilon}))}{\partial k_h} \right) - \frac{\partial (c(l_h, 0) - c(l_f, 0))}{\partial l_h} \right\} \frac{\partial l_h}{\partial v} + \frac{\partial J_g(\mathbf{k}^{t+\epsilon})}{\partial k_f} \frac{\partial l_f}{\partial v} > 0. \quad (9)$$

The inequality follows from the assumptions described above. Because the terms on the left side of (9) that correspond to the home firm's first order equation sum to 0, the inequality implies that the government's payoff is increasing in v in the neighborhood of $v = 0$. We conclude that a small subsidy increases welfare.

The same conclusion holds in the one-period version of this model. The intuition from the static models is that, for government intervention to be welfare improving, the government must be able to influence the decision of the home firm ($\partial l_h^*/\partial v \neq 0$) and the response of the foreign firm to a change in the home firm's decision ($\partial l_f^*/\partial l_h$) must be different than the response expected by the home firm. That is, government intervention is effective only if it corrects a "mistake" by the home firm about the effect of its actions on its rivals. For example, in a static Nash-Cournot game, each firm's believes its rival will not respond to a nonequilibrium decision, but the slope of its rival's best-response function is nonzero, so there is a role for government intervention.

For positive ϵ , $dl_f^*/dl_h \neq 0$, although the home firm takes l_f as given at a point in time. Therefore, for positive ϵ , there is a role for the government to use the policy v in the dynamic game. The home firm does not take into account the effect of its current level of investment on its rival's equilibrium level of investment.

B. The Government Loses Influence as Periods Become Shorter

We now show that shortening the government's period of commitment reduces the strategic value of an investment policy. This result is important because it provides a contrast with our earlier observation that the period of commitment does not alter the efficacy of output policies.

Equations (7a)-(7c) and the expressions for the elements of the Jacobian, H_{ij} , imply (see the Appendix for a proof)

Proposition 1: If the value functions $J_i^*(k)$ are differentiable in k for all values of ε , then

- (a) the effect of the industrial policy on the home firm's current investment remains bounded away from 0 as ε approaches 0;
- (b) the effect of the home government's industrial policy on the foreign firm's current investment is proportional to ε ; and
- (c) the slope of the foreign firm's best response function is proportional to ε .

In other words, $\partial I_h^*/\partial v$ is of a larger order of magnitude than ε , and $\partial I_f^*/\partial v$ and dI_f^*/dh are of the same order of magnitude as ε . As the length of a period, ε , becomes smaller, the government loses its ability to influence (indirectly) the foreign firm and, hence, cannot strategically intervene successfully. Proposition 1c implies that the foreign firm's best-response function, if plotted in (I_f, I_h) space with I_f on the vertical axis, is approximately flat for small values of ε . As this best-response function becomes perfectly flat, the noncooperative Nash and the Stackelberg equilibria converge. Thus, government intervention becomes ineffective as ε becomes small.

The home firm's response to a change in v , $\partial I_h^*/\partial v$, is of a larger order of magnitude than ϵ , so even as ϵ becomes small the government does not lose the ability to influence the home firm. If $\partial I_h/\partial v$ and $\partial I_f/\partial v$ were of the same orders of magnitude, the government could achieve its objective by increasing the value of v as ϵ decreases. Because they are of different orders of magnitude, increasing v has a non-negligible effect on I_h even for small values of ϵ , whereas it has a negligible effect on I_f . Therefore, if ϵ is small, but positive, the government needs to induce a large change in domestic investment (and thus incur a large adjustment cost) in order to cause a small change in foreign investment. Thus, for small ϵ , the strategic use of industrial policy is unattractive.

An alternative explanation for the decrease in the effectiveness of government policy as ϵ becomes small is that the government's first-mover advantage diminishes in a multiperiod game. In the current period of the dynamic game, the firms take the current value of v as given, but, by the Markov assumption, they recognize that future values of v will be determined by future values of k . Because they are able to influence the evolution of k , they can influence future values of v . In the one-period game, there is a clear sense in which the government is a Stackelberg leader vis-à-vis the firms, but this relation is ambiguous in a multistage game. At time t , the firms take v^t and k^t as given and choose $k^{t+\epsilon}$; at time $t+\epsilon$ the government takes $k^{t+\epsilon}$ as given and chooses $v^{t+\epsilon}$. Provided that the length of a period is non-negligible, there is some strategic value to industrial policies because the government retains the first-mover advantage *within* a period. However, the government loses this advantage across periods. This is why, in a dynamic setting, the strategic value of industrial policy is less than in static models.

To consider the limiting case as ε approaches 0, we make the additional assumption that the endogenous functions $J_i(\cdot)$ are analytic in ε , so that we can apply a first-order Taylor approximation to equations (4) to obtain the continuous time (stationary) dynamic programming equations

$$rJ_g(\mathbf{k}^t) = \max_v \pi_h(\mathbf{k}^t) - c(I_h^t, 0) + \frac{\partial J_g(\mathbf{k}^t)}{\partial k_h} I_h^t + \frac{\partial J_g(\mathbf{k}^t)}{\partial k_f} I_f^t, \quad (10a)$$

$$rJ_h(\mathbf{k}^t, v^t) = \max_{I_h^t} \pi_h(\mathbf{k}^t) - c(I_h^t, v) + \frac{\partial J_h^*(\mathbf{k}^t)}{\partial k_h} I_h^t + \frac{\partial J_h^*(\mathbf{k}^t)}{\partial k_f} I_f^t, \quad (10b)$$

$$rJ_f(\mathbf{k}^t, v^t) = \max_{I_f^t} \pi_f(\mathbf{k}^t) - c(I_f^t, 0) + \frac{\partial J_f^*(\mathbf{k}^t)}{\partial k_h} I_h^t + \frac{\partial J_f^*(\mathbf{k}^t)}{\partial k_f} I_f^t. \quad (10c)$$

It is difficult to characterize all solutions to the game because finding the unknown functions J_i requires solving a complex system of partial differential equations; however, we show in the Appendix:

Proposition 2: Suppose that there exists a Markov equilibrium to the continuous-time ($\varepsilon = 0$) investment game between the firms when the government is not a participant. Then there exists a Markov equilibrium to the continuous-time game involving the government and the two firms. In that equilibrium, the government is powerless. Its equilibrium investment policy is identically 0, and the firms behave as if the government were not a participant. This result does not hold for the discrete stage game, where $\varepsilon > 0$. There, the government typically has an incentive to intervene, and its participation affects the behavior of the firms.

According to Proposition 2, in the continuous-time game, if firms expect the government not to intervene in the future, it is optimal for the government not to intervene at this instant.¹¹ Proposition 2 does not exclude the possibility that there are Markov equilibria in which the government intervenes in the limit as ϵ approaches 0. Neither does it imply that the nonintervention Markov equilibrium is the limit of the sequence of equilibria obtained as ϵ becomes small and the horizon τ becomes large in the discrete stage game. Where subsidies are linear and profits and costs are quadratic, however, we show in the appendix that these results hold:

Proposition 3: The sequence of Markov equilibria of the linear-quadratic model converges to the no-intervention equilibrium described in Proposition 2 as the time horizon goes to infinity ($\tau \rightarrow \infty$) and $\epsilon \rightarrow 0$ under the assumption that a stationary equilibrium to the continuous time game exists.

C. Output and Industrial Policies

In Section II, we observed that the incentive to use output policies does not depend on the period of commitment. In Section III.B, we demonstrated that if only investment policies are used, they become ineffective as the period of commitment becomes small. If the government can use both output and industrial policies, it

¹¹ Proposition 2 is reminiscent of the "Coase Conjecture" (Coase 1972), which states that as a constant-cost durable goods monopolist's period of commitment shrinks to 0, its ability to exercise market power vanishes in a Markov equilibrium. This analogy emphasizes the importance of the Markov assumption. Ausubel and Deneckere (1989) analyze non-Markov equilibria for the durable goods model; the intuition they provide is also applicable to our model.

retains an incentive to use both, regardless of the period of commitment; however, its motive for using the industrial policy is non-strategic.

The output policies that the government will use in equilibrium depend on the firms' capital stocks. Consequently, even if the government were to resolve to not use industrial policies and to use only output policies in the future, the home firm's and the government's shadow values of the home capital stock would be different: $\partial J_h^*/\partial k_h \neq \partial J_g/\partial k_h$, because $W(k)$ is not identical to $\pi_h(k)$. In this case, Proposition 1 continues to hold but Proposition 2 does not. As a result, even as the period of commitment becomes infinitesimal, the government will want to use industrial policies. It does so because the output policies create a "distortion," which can be partly offset by means of the industrial policy.

In this case, industrial policy is not used strategically, as an indirect control on foreign investment, but is used to adjust home investment.¹² Thus, although the strategic benefits of investment policies are small when commitment is difficult, nonstrategic benefits may be significant. It follows from this argument that another reason for eliminating the use of output policies is that such policies increase the incentive for the use of investment subsidies.

IV. Numerical Examples

The ineffectiveness of industrial policies can be illustrated using a linear-quadratic model. In this model, which is described more fully in the Appendix, demand is linear, marginal cost is constant, and output is proportional to capital, so that the

¹² Other types of distortion, such as those caused by a difference between private and social cost of an input, would also create an incentive for the use of investment policy.

profit function is quadratic in k and the cost of adjustment ($\frac{1}{2}\delta l^2$) is quadratic in investment. The equilibrium decision rules are obtained by dynamic programming. The recursive equations that determine the equilibrium are too complicated to admit closed form analysis, but they can be solved numerically.¹³

Table 1 shows the percentage increase in each agent's payoff resulting from optimal intervention by the government. In this example the difference between the demand intercept and the constant marginal cost equals one, the cost of adjustment is $\frac{1}{2}l^2$ (that is, $\delta = 1$), and the continuous discount rate, r , is 0.05. We choose a unit of time to equal 1 year, so if ϵ equals one, the discount factor, $\beta = e^{-r\epsilon}$, is approximately 0.95. For $\epsilon = 0.1$, the length of the period of commitment is approximately five weeks. We use a time horizon, τ , of 15 years and the initial condition is $k = (1/3, 1/3)$, the noncooperative equilibrium in the static Nash game with no cost of adjustment. The first row of Table 1 gives the percentage increases in agents' welfare in the static model, which is included for purposes of comparison. Government intervention increases domestic welfare (the home firm's profits less the transfer) by 12.5 percent in the static model. In the dynamic game when the period of commitment, ϵ , is one year, intervention increases domestic welfare by 6.4 percent. When the period of commitment is 0.1 year, government intervention increases domestic welfare by less than 1 percent. Government intervention increases the home firm's profits more than it does domestic welfare, because the firm receives a positive subsidy, as in the static game.

The table demonstrates two important features of the general model. First, even for a fairly long period of commitment, the benefits of government intervention

¹³ Details of the algorithm are available from the authors upon request.

are overstated by the static model. For example, for $\varepsilon = 1$, where the government can commit for a year, benefits are only half those of the static model. Second, as the period of commitment shrinks, the benefits of government intervention become negligible.

If the government could commit to a sequence of future subsidies, it would retain its first-mover advantage and could increase home welfare by more than in the subgame perfect equilibrium above. A weaker form of commitment, studied by Driskell and McCafferty (1989b), is for the government to announce a constant subsidy per unit of investment for all periods. With this subsidy, the gross transfer from the government to the firm changes over time, as the level of investment changes, and approaches 0 in the steady state. It is not obvious whether the government would prefer this weaker form of commitment or the Markov rules. The former entails less flexibility because the government has a single choice variable. The optimal fixed subsidy depends on the initial condition; the Markov rules are independent of the initial condition.

The optimal fixed subsidy F (shown in the first row of Table 2, for the base parameters $\varepsilon = 1$ and $\tau = 100$) is relatively insensitive to the initial levels of capital. In the first period, the present discounted value of the government's payoff in the initial period when it chooses the optimal fixed subsidy (second row) is greater, for any initial k , than the government's payoff in the initial period when v is chosen according to the Markov rules (last row). Thus, in this linear-quadratic example, the benefits from committing to a fixed F more than compensate for the loss of policy flexibility. Similarly, for any k , the welfare in the steady state under the fixed subsidy is greater than with the variable industrial policy.

For all initial conditions, with a fixed subsidy, the steady-state capital of the home firm, k_h , is higher and the foreign firm's level, k_f , is lower than with the Markov policy. These steady-state levels of capital are fairly close to the Stackelberg equilibrium in the corresponding static game, $\mathbf{k} = (0.5, 0.25)$, but k_h is always less than 0.5. Although the government does not obtain as favorable a steady state in the dynamic game as in the static equilibrium, it comes closer to doing so with the fixed policy rule than with the Markov rules.

V. Summary and Conclusions

In static and two-period markets, previous models show that governments have strategic incentives to use export or production subsidies or taxes to intervene in imperfectly competitive international markets, shifting profits from foreign competitors to the domestic industry. Except for primary materials, however, output policies violate either the spirit or the letter of international agreements, and are politically unattractive. As a result, many policy makers advocate the use of industrial policies. Using a dynamic model, we show that, if the government is unable to make binding commitments about its future use of industrial policy, these policies are of limited strategic use. In contrast, the efficacy of output policies is not diminished by a limited period of commitment. This fundamental difference between industrial and output policies had been obscured in previous static models.

The intuition from the static models remains qualitatively correct in a dynamic model: The circumstances that encourage output subsidies also encourage industrial policies that implicitly subsidize the domestic industry. The static models, however, exaggerate the benefits of industrial policies in a multiperiod market. The strategic benefits from industrial policy are negligible if the government can only make commit-

ments for short periods. The use of output policies gives the government a nonstrategic incentive to use investment policies, even if the period of commitment is small.

Our analysis suggests that GATT negotiators have, perhaps inadvertently, been correct in focusing their efforts on attempts to limit the use of output policy. Industrial policy is likely to be less of a threat to free trade than output policies, and the use of output policies provide an additional motive for using industrial policies.

Our assumption that the government and the firms have the same period of commitment is an unnecessary restriction and, in many markets, unrealistic. Our analysis does not turn on whether the period of commitment is the same for all players but on whether the government's ability to commit is limited. One would expect such limitations in industries that are changing rapidly, and for which future conditions are very uncertain. In these cases it is difficult for the government to commit credibly to future policies, because agents recognize that as circumstances change, the government will be tempted to change its policy. In other words, agents recognize that the government's policy is state contingent. High-tech industries, such as computer chips, fit this description, and it is precisely these industries for which the sentiment in favor of industrial policy has been strongest. This analysis suggests that industries that replace capital at wider intervals, such as traditional manufacturing, would be better candidates for the application of industrial policy. Indeed, most developed countries use industrial policies in textiles and shipbuilding.

Both industrial and output policies are even less likely to be useful strategically when foreign governments can intervene, firms of other countries can enter the world market, or a variety of other assumptions maintained above (and in most static models) are dropped. Thus, the strategic use of output and industrial policies should

be rejected both because they are beggar-thy-neighbor policies and because they are likely to be ineffective in achieving that end.

Appendix: Proofs

Proof of Proposition 1: The assumptions that the partial derivatives of the value functions exist and are finite for all values of ϵ imply

$$\lim_{\epsilon \rightarrow 0} H_{22} = \frac{-\partial^2 c(l_f, 0)}{\partial l^2},$$

$$\lim_{\epsilon \rightarrow 0} H_{21} = 0,$$

$$\lim_{\epsilon \rightarrow 0} |H| = \frac{\partial^2 c(l_h, v)}{\partial l^2} \frac{\partial^2 c(l_f, 0)}{\partial l^2}.$$

Thus, $\partial l_h^*/\partial v$ approaches $-(\partial^2 c(l_h, v)/\partial l \partial v)/(\partial^2 c(l_h, v)/\partial l^2) > 0$ and $\partial l_f^*/\partial v$ approaches 0 as ϵ approaches 0, which establishes parts (a) and (b) of the proposition. Part (c) is true because the right side of (7c) approaches 0 as ϵ approaches 0. ||

Proof of Proposition 2: Suppose that the function $M_i(\mathbf{k})$ gives the equilibrium payoff to Firm i when v is identically 0; that is, $M_i(\mathbf{k})$, $i = h, f$, solves the pair of partial differential equations given by (10b) and (10c) when $v \equiv 0$ (and the maximization has been performed). Then $J_g(\mathbf{k}) \equiv M_h(\mathbf{k})$ and $J_i(\mathbf{k}) \equiv M_i(\mathbf{k})$, $i = h, f$, must also represent a solution to (10a) - (10c). To verify this result, we first note that, in the limit, $\partial l_f/\partial v = 0$ by Proposition 1b. We then substitute the "trial solution" $J_g(\mathbf{k}) \equiv M_h(\mathbf{k})$ into the limiting form of (8) and use (5) with $i = h$ and $v_h = 0$. By inspection, $v \equiv 0$ satisfies the government's first-order condition. Because, by assumption, $M_i(\mathbf{k})$ gives the value of the game to Firm i when $v \equiv 0$, it must be the case that $J_g(\mathbf{k}) \equiv M_h(\mathbf{k})$ gives the value of the game to the government when $v \equiv 0$. Further, as we have seen, for this value function, $v \equiv 0$ is optimal for the government.

To verify that the non-intervention policy ($v \equiv 0$) is typically not part of a Markov equilibrium to the discrete stage game ($\varepsilon > 0$), we use a proof by contradiction. Let $\varepsilon > 0$ and suppose that the firms and the government expect that v will be zero in all future periods. Then $J_g(k_{t+\varepsilon}) \equiv J_h^*(k_{t+\varepsilon})$ so the term in brackets in (9) is 0 when evaluated at $v = 0$; however, the second term on the left side is nonzero, so a current value of $v = 0$ does not satisfy the government's first-order condition. Consequently, $v \equiv 0$ cannot be a Markov equilibrium when $\varepsilon > 0$ because the government has some leverage over I_f . ||

To prove proposition 3, we first state and prove two lemmas. We start by examining equilibrium investment behavior when linear taxes are used. For a linear tax, $c(I_h, v) = c^*(I_h) - vI_h$, where c^* is the cost of investment in the absence of an industrial policy. The flow of transfers from the government to the home firm is $T(I_h, v) = c(I_h, 0) - c(I_h, v)$, so the average and the marginal transfer are equal under a linear tax: $\partial T(\cdot)/\partial I_h = T(\cdot)/I_h$. Because, in equilibrium, T is a function of the current value of k , the present value of the future equilibrium flow of the transfer is

$$V(k^0) = \int_0^\infty e^{-rt} T(k^t) dt.$$

The function $V(k)$ satisfies the partial differential equation

$$rV(k) = T(k) + \frac{\partial V}{\partial k_h} I_h + \frac{\partial V}{\partial k_f} I_f. \quad (A.1)$$

Using these intermediate results, we obtain:

Lemma 1: If the government uses a linear tax in the continuous time game ($\varepsilon = 0$), then the function $V(k)$ is of the form

$$V(k_f, k_h) = Y(k_h) \exp \left[r \int_{I_f(\bar{k}_f, k_h)}^{k_f} \frac{dk_f}{I_f(k_f, k_h)} \right], \quad (\text{A.2})$$

where Y is an unknown function of k_h and $I_f(k)$ is the equilibrium investment rule of the foreign firm.

Proof: From (10a), the government's first-order condition is

$$\left[-\frac{\partial c(I_h, 0)}{\partial I_h} + \frac{\partial J_g}{\partial k_h} \right] \frac{dI_h}{dv} = 0, \quad (\text{A.3})$$

which uses the result from Proposition 1b that $\partial I_f / \partial v = 0$. From the definition of the government's maximization problem, $J_g(k) \equiv J_h^*(k) - V(k)$. Thus, the government's payoff equals the firm's payoff less the present value of the flow of future transfers. As a result, $\partial J_g / \partial k_h = \partial J_h^* / \partial k_h - \partial V / \partial k_h$. Substituting this relation and the home firm's first-order condition into (A.6), we obtain

$$\left[-\frac{\partial T(I_h, v)}{\partial I_h} - \frac{\partial V}{\partial k_h} \right] \frac{dI_h}{dv} = 0, \quad (\text{A.4})$$

where $T \equiv c(I_h, 0) - c(I_h, v)$. Using (A.4) to eliminate $\partial V / \partial k_h$ from (A.7) and then noting the equivalence between marginal and average taxes, we find that

$$\left[rV - \frac{\partial V}{\partial k_f} I_f \right] \frac{\partial I_h}{\partial v} \frac{1}{I_h} = 0. \quad (\text{A.5})$$

From Proposition 1a, the term outside the brackets in (A.8) is nonzero outside the steady state, so the term in brackets in (A.8) must vanish. The general solution to the resulting first-order linear partial differential equation is given by (A.5).||

We now consider the special case where the profit functions $\pi_i(\cdot)$ and the cost functions $c_i(\cdot)$ are both second-order polynomials, and the government uses a linear tax. The investment adjustment cost function is

$$c(l_i, v_i) = \left(\frac{\delta}{2} l_i - v_i \right) l_i$$

where the parameter δ determines the convexity of costs and the home government subsidizes each unit of investment by the amount v .¹⁴ By assumption, firms produce at capacity in the intra-period game; by appropriate scaling, one unit of output is produced by one unit of k_i . The restricted profit function is

$$\pi_i = (a - k_f - k_h) k_i$$

where a is price minus constant marginal costs. For this linear-quadratic model, we have

Lemma 2: For the linear-quadratic model with a finite horizon, τ , and $\varepsilon > 0$, if the value functions in the Markov equilibrium exist, they are linear-quadratic and the endogenous decision rules that determine v , l_h , and l_f are linear in k .

¹⁴ If the firm buys capital, a linear term, ξl_i , should be added to the cost function, where ξ is the social cost of a unit of capital. If, however, the firm rents capital, as with human capital, then it is reasonable to set $\xi = 0$ and put the rental cost in the restricted profit function π_i . We take this latter approach in the text to reduce the number of parameters.

The proof of this lemma, which is based on the algorithm used to compute the numerical examples in section IV, is available from the authors. In the proof, it is first established that in the last period the value functions are quadratic and the decision rules are linear; and is then shown by induction that this result holds at every previous stage. Existence can be established for specific parameter values using numerical methods as discussed in the text.

Proof of Proposition 3: From Lemma 2, each element of the sequence of equilibria involves quadratic value functions and linear decision rules. Because the limiting value functions are quadratic, and, by definition, $J_h(k) = J_g(k) + V(k)$, the function $V(k)$ must be a polynomial of order two or less: $V(k) = \alpha + \theta'k + k'\gamma k$, where α , θ , and γ are, respectively, a scalar, a vector, and a matrix, and the transpose is indicated by a prime. Moreover, the control rule, $I_f(k) = h + g'k$, is a linear function, where h is a scalar and $g' = (g_h, g_f)$ is a vector. Substituting this linear control rule into the formula for V in (A.5) and integrating gives $V(k_h) = V(k) (h + g'k)^{-r/g_f}$.

Because $V(k)$ is quadratic, it follows that

$$V(k_h) = (\alpha + \theta'k + k'\gamma k) (h + g'k)^{-r/g_f}. \quad (\text{A.6})$$

In order for this relation to hold identically, the partial derivative of the right side, with respect to k_f , must be identically equal to 0. Taking this derivative and setting the result equal to 0 (after factoring out the non-zero term $(h + g'k)^{-(r+g_f)/g_f}$) produces an expression that is quadratic in k and involves the parameters α , γ , θ , h , and g . In order for this expression to vanish, the coefficients of the terms involving k must vanish.

Under the hypothesis that g_f is not equal to either r or $r/2$, we can verify that the requirement that the coefficients of orders of k vanish, implies that α , γ and θ are all 0; hence, V is 0 for all values of k as was to be shown.

We now need to verify the hypothesis that g_f is equal to neither r nor $r/2$. We do this by showing that g_f is non-positive. To demonstrate this, we note that g_f is positive if and only if the foreign firm's (quadratic) value function is convex in k_f . This statement can be verified by checking the foreign firm's linear-quadratic dynamic programming equation. We, therefore, need to establish that the foreign firm's value function is not convex in k_f . Suppose, to the contrary, that it was convex. Then, it would be possible to make the value of the foreign firm's program arbitrarily large by choosing an initial value of k_f sufficiently large and choosing $k_h = 0$. However, the value of the foreign firm's program is certainly bounded above by π^m/r , where π^m is the steady state flow of monopoly profits. Therefore, the value function is not convex and g_f is not positive.||

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Table 1

Benefits Vary with the Period of Commitment (ϵ)
(Percentage Increase in Benefits due to Intervention)

ϵ	g	h	f
∞^*	12.5	125	-43.7
15	12.4	49.3	-43.5
1	6.4	18	-23.6
0.1	0.7	1.26	-3.43
0.001	0.007	0.01	-0.035

* The row for $\epsilon = \infty$ is calculated using the static game.

Table 2
Optimal Fixed Subsidies

	Initial Values (k_h, k_f)						
	(0,0)	(0,.5)	(1/3,1/3)	Nash	(.5,0)	(.5,.5)	(.4,.1)
F	3.68	3.64	3.72	3.72	3.77	3.74	3.75
PVW*(1)	2.36	2.30	2.38	2.38	2.44	2.36	2.42
PVW(1)	2.29	2.23	2.31	2.30	2.37	2.28	2.35

PVW*(1) = present value of welfare in the first period for the optimal fixed F.
 PVW(1) = present value of welfare in the first period when the government chooses v each period.
 PVW*(∞) = present value of welfare in the steady state for the optimal fixed F
 ≈ 2.40 (for all initial values).
 PVW(∞) = present value of welfare in the steady-state when the government chooses v each period
 ≈ 2.33.
 Nash = $(k_h, k_f) = (.35, .35)$
 The steady-state when the government chooses F is $(k_h, k_f) \approx (.48, .28)$.
 The steady-state when the government chooses v each period ≈ (.44, .30).