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# ENERGY TAXES AND AGGREGATE ECONOMIC ACTIVITY

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## EXECUTIVE SUMMARY

This paper shows that the output losses from energy taxes are significantly larger than usually computed when due account is taken of imperfect competition among energy-using firms. Even with perfect competition among these firms, the loss in GNP is of the same order of magnitude as the revenue raised by these taxes. However, in the presence of imperfect competition the output losses are much higher. There are particularly large transitory losses in the immediate aftermath of energy-price increases when firms act as implicitly colluding oligopolists. These losses become considerably smaller if energy taxes are phased in. We also show that taxes that affect only household consumption of energy have much smaller effects. In particular, for the empirically plausible parameter values we consider, such taxes have no effect on employment or output in the non-energy sector.

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## 1. INTRODUCTION

As part of his address to a joint session of Congress on February 17, 1993, President Clinton proposed a broad-based energy tax as a central part of his plan to reduce the size of the U.S. government budget deficit. Had this Btu tax been enacted, crude oil eventually would have been subject to an approximately 21 percent tax, coal to a 25.7 percent tax, and natural gas to a 16 percent tax. Somewhat lower taxes would have applied to hydroelectricity and nuclear power. The political resistance to this energy tax, however, was intense, and when the dust settled, all that was enacted was about a 4 percent tax on gasoline.

One of the reasons advanced for resistance to the energy tax was concern about its impact on production and employment in U.S. industry. Indeed, existing studies of the effect of carbon taxes (Goulder 1992, 1993a, 1993b; Jorgenson and Wilcoxon, 1993) suggest that the reductions in GDP caused by these taxes are comparable to the amount of revenue they raise. To demonstrate that this loss is more onerous than the losses caused by other taxes, these authors show that GDP still falls substantially even if the revenues from the carbon tax are used to reduce existing labor income taxes.<sup>1</sup> That energy taxes are so deleterious may seem surprising, since energy consumption is a relatively small fraction of GDP. But the share of energy costs in total costs does not affect the analysis because the small share of spending on energy also reduces proportionally the revenue raised by a given *ad valorem* tax rate. Neither does our analysis hinge on the fact that, in practice, other inputs are used to produce energy. Thus, the cost of energy taxes we discuss is unrelated to Diamond and Mirrlees's (1971) proof that it is inefficient to tax intermediate inputs; energy is actually a raw material in our model since we neglect extraction costs. Rather, the cost of energy taxes results from the fact that, unlike other raw materials such as labor, the supply of energy is relatively elastic. As a result, the quantity of the energy input falls substantially in response to a tax, instead of the factor price simply being forced down.

In this paper, we argue that the contractionary effects of energy taxes on energy-using industries are even larger than is usually computed,

<sup>1</sup> Of course, an appropriately structured energy tax also has a benefit that other kinds of taxes do not, which is the provision of a disincentive for activities with harmful external effects. This benefit, rather than the search for additional sources of government revenue, is the main reason for recent discussion of "carbon taxes." From this point of view, an energy tax can actually improve efficiency. Because we do not here attempt an overall evaluation of the welfare consequences of an energy tax, we do not attempt to quantify such effects. For an attempt to do so, see Goulder (1993b).

once due account is taken of imperfect competition in those industries.<sup>2</sup> The presence of imperfect competition implies that the price of output is above the marginal cost of production. Thus, the social benefit from increasing output by one unit exceeds the social cost of doing so. This wedge implies that a reduction in output has more deleterious welfare consequences in the presence of imperfect competition. Thus, the pre-existing distortion due to the lack of perfect competition raises the welfare costs of any particular output reduction, whatever its origin. Welfare costs are not our main focus here, however. Instead we study the degree to which output falls and show that this too is larger with imperfect competition.

The reason is twofold. First of all imperfect competition implies that the marginal product of any factor, including energy, exceeds its price. Thus, the reductions in energy and other inputs that result from energy taxes reduce GNP by more than one would estimate judging simply from these inputs' measured cost shares.

Secondly, if the tax change increases the degree of market power of firms in their product markets, the firms increase the extent to which they mark up their prices relative to their marginal costs, which results in a contraction of the equilibrium level of production, just as if a tax on inputs had increased those marginal costs. We show that even a very small increase in market power can have a large effect on the predicted output decline, because the mark-up increase is like a tax on all inputs, not just energy, and that a particular model of endogenous mark-up determination (the model of oligopolistic pricing previously used in Rotemberg and Woodford, 1991, 1992, 1993) can imply a temporary increase in market power following an energy tax increase, though the effect is transitory even in the case of a permanent tax increase. Furthermore, this effect is even stronger if one allows for uncertainty about the permanence of the tax change.

We also show that allowing for imperfect competition has important consequences for evaluation of the relative merits of alternatively structured energy taxes. In particular, we show that gradual phase-in of an energy tax mitigates the contractionary effects in the short run, to an even greater extent than revenues are reduced over that same period; and this effect is even more pronounced when imperfect competition is taken into account.

Our method is to numerically solve a calibrated, general equilibrium

<sup>2</sup> Judd (1993) shows that imperfect competition also affects the optimal tax on capital income. His analysis differs from ours because capital goods are intermediate inputs whereas we treat energy as a raw material.

simulation model, under alternative assumptions about product market structure. Our model decomposes energy into energy purchased directly by households and energy bought indirectly via the purchase of other produced goods, allowing us to analyze the difference between taxes on all energy use and taxes on directly consumed energy.

This paper is related to Rotemberg and Woodford (1993), in which we considered the ability of a similar range of alternative models to explain the large declines in U.S. output that followed pre-1980 increases in the price of oil. We showed that it was easiest to explain these contractions of output, as well as the simultaneous declines in real wages, if one viewed firms not only as having market power but as implicitly collusive.<sup>3</sup> The numerical calibration of the "variable mark-up" model considered here matches that of the model shown in the previous paper to best fit the observed effects of oil-price shocks. This match gives us some reason to suppose that imperfectly competitive effects of the size assumed in our simulations may actually be present in the U.S. economy.

Section 2 sets the stage by describing the U.S. energy market. Section 3 discusses the behavior of the firms that use this energy to produce final output and also gives an intuitive explanation for the importance of imperfect competition in determining the output losses caused by energy taxes. Section 4 then describes the rest of our simulation model. Sections 5 and 6 then present the model's numerical predictions regarding, respectively, the long-run and short-run effects of an unexpected permanent increase in energy taxes. In Section 7 we take up the effect of predicted changes in energy taxes. We thus consider both the effect of phased-in taxes as well as the effects of taxes that are expected to be repealed. Section 8 concludes.

## 2. THE U.S. ENERGY MARKET

Four types of products account for the vast bulk of energy consumption: coal, natural gas, petroleum products, and electricity. For our purposes, we wish to obtain an energy aggregate. Our common approach is to add together the Btu's contained in all four sources of energy. This would make sense if the products were perfect substitutes in the sense that a Btu from one source is as useful as a Btu from another. However, in practice, the price per Btu is rather different for different sources of energy. In particular, it is higher for oil than for coal. For that reason, our

<sup>3</sup> The same model of oligopolistic pricing is shown in Rotemberg and Woodford (1991) to be useful in explaining cyclical variations in real wages, and in Rotemberg and Woodford (1992) to be useful in explaining the effects of military purchases on real wages.

aggregate is obtained by adding together the expenditure on these four products. This strategy too is strictly appropriate only if the products are perfect substitutes. However, it allows the Btu's from one source to be less useful than those from another.

The aggregation of these four energy sources is complicated by the fact that coal, gas, and petroleum products are used in the generation of electricity (though some electricity is also generated from other sources). It would thus be incorrect to simply add together the values of coal, natural gas, petroleum products, and electricity sales. What we do instead is to count only the coal, natural gas, and petroleum products that are not sold to electric utilities.

Table 1 presents data on the sales of these four products in 1989. Most of coal is used for electric generation. We valued the 100 million metric tons that are consumed in other sectors at the average CIF price paid by electric utilities, namely \$30.43 per ton. To value both domestically produced and imported crude oil, we used the average import price of \$16.54 per barrel. Electric utilities do not use crude oil directly. Rather, they buy a combination of different petroleum products. Over half of these are made up of residual fuels whose average price was \$18.65 per

**TABLE 1.**  
*Energy Use in the U.S. Economy.*

	Quantity	Price	Value (billion\$US)
<b>Coal</b>			
Production	1,000 short tons		
Exports	100 short tons		
For electricity	800 short tons		
Other uses	100 short tons	30 / ton	3
<b>Petroleum</b>			
Production	2,707 million barrels	16.54 / barrel	44.77
Imports	2,223 million barrels	16.54 / barrel	36.77
For electricity	196 million barrels	18.65 / barrel	3.70
<b>Petroleum and coal processing</b>			
Value added			36.70
<b>Natural Gas</b>			
Total revenues			69.07
For electricity	2.78 trillion cubic feet	2200 / cubic feet	6.10
Other uses			62.93
<b>Electric Utilities</b>			
Total revenues			184.90
Total purchases			365.41

barrel. We assigned this price to the entire volume of petroleum products purchased by electric utilities. Because this price is higher than the price of crude oil, electric utilities are effectively also purchasing some of the value added of the refining sector. This fact does not pose any conceptual difficulties because we add the entire value added of the petroleum and coal products sector to our aggregate.

In the case of natural gas, we start with the revenues of the industry.<sup>4</sup> We then subtract the gas purchased by electric utilities using the average price paid by them for natural gas.<sup>5</sup> Finally, we add the total revenues by electric utilities to our aggregate. We conclude that energy consumption in 1989 was equal to \$365.4 billion, or about 6.6 percent of GDP. Of this total, imported oil accounts for \$62.3 billion, or 0.17 of the total, and 1.1 percent of GDP.

We have less accurate data for the breakdown of energy use between direct household use and non-energy production. In the case of electricity revenue, we know that approximately one third comes from residential sales. In the case of the gas sector, we know that residential sales account for \$25.4 billion in 1990, or 40 percent of the total revenues counted above. Office of Technology Assessment (1990) reports total U.S. energy use in 1985 as 74.9 quads (quadrillion Btu's), of which 28 are reported for direct household energy use, 37 percent of the total. However, government direct use is also reported as 3 quads, so that uses in production (assuming that all energy use other than the two categories just mentioned should be counted as such) are only 59 percent of the total. Assuming that 0.6 of the costs calculated in the previous paragraph are energy inputs into non-energy production, we obtain energy costs with a value of 4 percent of GDP. Subtracting out the 5.5 percent of GDP representing value added by the domestic energy industry (6.6 percent minus 1.1 percent from above), value added in the non-energy sector represents 94.5 percent of GDP, so that energy costs in that sector are 4.2 percent of value added. The energy sector is thus not an extremely large one. It is thus somewhat surprising that taxes on the output of this sector have such large effects on aggregate activity.

### 3. WHY IMPERFECT COMPETITION MATTERS

We show in the following that the effects of energy taxes on aggregate activity are much larger when account is taken of imperfect competition among the firms that purchase energy. In this section we provide some

<sup>4</sup> From the Survey of Current Business.

<sup>5</sup> From the 1990 Annual Energy Survey.

intuition for this result by considering a simplified model. Suppose that output is produced with just two inputs, labor  $H$  and energy  $E$ . In particular, each firm has a Cobb-Douglas production function of the form

$$Y_i^t = A(H_i^t - \bar{H})^{1-\alpha}(E_i^t)^\alpha \tag{1}$$

where  $Y_i^t$  is the output of firm  $i$  in period  $t$ , while  $H_i^t$  and  $E_i^t$  represent its labor and energy inputs, respectively. The parameter  $\bar{H}$  represents a fixed amount of "overhead" labor needed to carry out any production at all. The assumption of fixed costs ensures that the production function exhibits increasing returns to scale in the sense that average costs exceed marginal costs. Our model requires us to assume such increasing returns to scale. Otherwise, it is impossible to reconcile the gap between price and marginal cost implied by the absence of perfect competition with the apparent absence of pure profits in U.S. industry.

Given the production function in equation (1), the marginal product of energy is  $\alpha Y_i^t / E_i^t$  or, equivalently,  $\alpha A[(H_i^t - \bar{H})/E_i^t]^{1-\alpha}$ . Under perfect competition, this marginal product is set equal to the real price of energy, that is, to the price of energy divided by the price of output. But, under imperfect competition, the price of output is higher relative to marginal cost. In this case one instead obtains

$$\alpha A \left( \frac{H_i^t - \bar{H}}{E_i^t} \right)^{1-\alpha} = \mu_i^t p_{Et} \tag{2}$$

where  $\mu_i^t$  is the ratio of firm  $i$ 's price to its marginal cost in period  $t$ , and  $p_{Et}$  is the real price of energy at  $t$ . Equation (2) has two implications, both of which make energy taxes more contractionary in the case of imperfect competition. First, a high  $\mu_i^t$  implies a higher marginal product of energy, given any observed real energy price. The fact that the marginal product of energy is higher implies that any given reduction in energy inputs lowers output by more under imperfect competition.

To see this more formally, note that equation (1) implies that a 1 percent reduction in  $E$  lowers output by  $\alpha$  percent. The question is what value should be assigned to  $\alpha$ . Under perfect competition, equation (2) implies that it equals the energy share  $p_{Et}E_i^t/Y_i^t$ , which is the usual method of assigning a numerical value to this parameter. But with a mark-up different from one, the energy share instead equals  $\alpha/\mu$ . Thus a higher mark up implies a higher value for  $\alpha$ , and thus a higher elasticity of output with respect to energy, given an observed energy share (as calculated in the previous section).



This result still leaves the question of whether the energy input falls more under perfect or under imperfect competition. A second implication of equation (2) is that, holding employment fixed, the energy input falls more under imperfect competition. Holding employment fixed is reasonable if one expects labor to be supplied inelastically in the long run. Then (2) implies that a 1 percent increase in the price of energy will lead to a  $1/(1 - \alpha)$  percent reduction in the demand for energy. The larger this fall, the larger is one's estimate of  $\alpha$ , and thus the departure from perfect competition.

The intuition for this result is the following. Suppose that one observes that, with a given amount of employment, an economy produces seven units of output with 50 units of energy input. Figure 1 displays two possible Cobb-Douglas production functions that could have led to this outcome. In the first  $\alpha$  is equal to 0.5, whereas in the second  $\alpha$  is equal to 0.7. They differ in that the marginal product of energy at the observed level of output is different. The function with  $\alpha$  equal to 0.5 might be inferred, given the observed real price of energy, if one believed that firms are perfectly competitive, and the function with  $\alpha$  equal to 0.7 might be inferred under imperfect competition. An important difference between the two functions is that the one with  $\alpha$  equal to 0.7 is less bowed toward the origin, less concave. Its smaller concavity is dic-

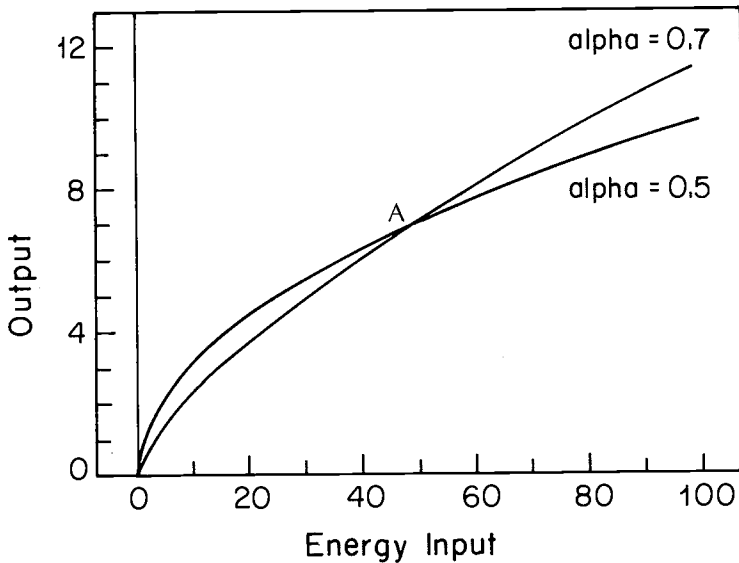


FIGURE 1. *Estimated Production Functions.*

tated by the fact that although both curves go through the origin and through point A, it is steeper at A. The smaller concavity of the  $\alpha = 0.7$  function implies that a given percentage change in its slope, that is, in the marginal product of energy, must lead to a larger change in the energy input.<sup>6</sup> Thus imperfect competition implies a larger change in the energy input from a given percentage tax on energy, given observed values for output, the energy input, and the real price of energy at point A.

Under imperfect competition, the increase in energy taxes also has the potential of raising the equilibrium mark-up  $\mu_i^i$ . It follows immediately from (2) that an increase in the mark up will, with constant employment, lead to a further contraction in energy inputs and thus in output. Our simulations below show that in the case of a model of oligopolistic collusion, an increase in the energy tax does cause an increase in the equilibrium mark up. In this case, imperfect competition has an even greater effect on our results.

#### 4. A SIMULATION MODEL WITH IMPERFECTLY COMPETITIVE PRODUCT MARKETS

As was noted previously, our simulation model is similar in structure to the one used in Rotemberg and Woodford (1993) to analyze the effects of oil price shocks. Some modifications are required, however, for our present purposes. In particular, our interest in permanent tax changes requires that we take account of the effects of entry and exit in the long run. We also distinguish here between the use of energy in production and direct household use of energy.

The production function in our simulation model is much more general than the one used in the previous section for illustrative purposes. Like Goulder (1992), we assume that each firm in the private non-energy sector produces goods each period with a production function of the form,

$$Y_t^i = Q(V(K_t^i, z_t H_t^i), G(E_t^i, M_t^i)), \quad (3)$$

where  $K_t^i$  and  $M_t^i$  represent, respectively, firm  $i$ 's capital and materials inputs at time  $t$ , and  $z_t$  indicates an exogenously given labor-augmenting technology factor. The aggregator  $Q$  for value added  $V$  and the intermediate input aggregator  $G$  is assumed to exhibit constant returns to scale, as

<sup>6</sup> The fact that the curve with  $\alpha$  equal to 0.7 has both a steeper slope at point A and a flatter slope at low values of the energy input implies that the slope of this curve rises by less in percentage terms as one decreases the energy input from point A to a low positive value.

is the aggregator  $G$  for the intermediate inputs  $E$  and  $M$ . In the competitive case, we also follow Goulder in assuming constant returns to scale for the value added production function  $V$ . However, in the case of imperfect competition, and hence output prices higher than marginal cost in equilibrium, constant returns to scale would again imply the existence of pure profits. We do not wish to let such profits exist, at least not in the long-run, steady-state growth path. Hence in the case of imperfect competition, we assume an increasing returns technology, so that average costs in excess of marginal costs can reconcile market power with free entry, as in Chamberlin's (1933) celebrated model of monopolistic competition. As in Rotemberg and Woodford (1992), we assume a value added production function of the form,

$$V(K,H) = F(K,H) - \Phi, \quad (4)$$

where  $F$  is homogeneous of degree one, and  $\Phi$  is a positive constant. (We may assume that equation (4) applies equally in the competitive case, but with  $\Phi = 0$ .) The constant  $\Phi$  indicates the presence of fixed costs (overhead), and the homogeneity of  $F$  implies that marginal costs are independent of scale.

We assume that  $z_t$  grows exogenously at a rate  $g > 0$ . The tax changes that we consider below will all be analyzed in terms of perturbations of the equilibrium around a steady-state balanced-growth path that the economy would follow in the absence of the tax changes. Along this balanced-growth path, the aggregate capital stock, energy inputs, materials inputs, and non-energy output all grow at the same rate  $g$  (the exogenous rate of technical progress), while aggregate hours worked remain constant (so that the effective labor input,  $z_t H_t$ , grows at the same rate as the other factors).<sup>7</sup> In order for fixed costs to remain a constant fraction of total costs along this balanced growth path, it is necessary for us to assume (in the case of imperfect competition) that the number of firms  $N_t$  grows at the same rate  $g$ , so that the scale of production by each firm remains constant. We assume that entry is through the introduction of new differentiated goods, so that the degree of market power of each firm remains the same (again, as in Chamberlin's model). The details of the process of entry and the conditions needed to ensure that our steady state with entry has zero profits are considered in Appendix 1.

We consider only symmetric equilibria in which the production plans of all firms are identical, so that  $Y_t^i = Y_t/N_t$ ,  $E_t^i = E_t/N_t$ , and so on, where

<sup>7</sup> In assuming a balanced-growth path in which (per capita) hours worked remain constant, we follow numerous papers in the real business cycle literature; see, for example, King, Plosser, and Rebelo (1988). See also the footnote on page 171.

the variables without  $i$  superscripts refer to aggregate quantities for the private non-energy sector. The maximization of profits by these individual firms implies, as before, that the marginal product of each factor is equal to the product of this factor's real price and the mark up of price over marginal cost. Though there are four conditions of this type, we will be interested mainly in the one that is analogous to (2). This condition relates to the marginal product of  $G$  and requires that

$$Q_G(V, G) = \mu_i p_{G_i} \quad (5)$$

where  $p_{G_i}$  is a price index for the aggregate  $G_i$ , and  $\mu_i$  is the common mark-up of all firms in a symmetric equilibrium. The price index  $p_{G_i}$  depends on the prices of energy and materials relative to the price of non-energy output. In a symmetric equilibrium the price of this output is the same for all firms, even in the case of imperfect competition. Because each firm's materials are some other non-energy firm's output, the price of materials inputs is identical to the price of non-energy output. Energy inputs are assumed to be in perfectly elastic supply at a fixed relative price  $p_E$  (which we imagine to be fixed on a world market, and so independent of changes in tax policy and production plans in the United States). Thus,  $p_{G_i}$  depends only on the tax rate on energy,  $\tau_E$ , whose effects we wish to analyze. Because we assume that  $p_E$  is fixed in all of our ensuing experiments, there is no distinction between the case of an *ad valorem* tax and a specific tax such as the Btu tax that was recently proposed.

In our simulations, we consider three different types of product market structure for the non-energy producers. In the case of perfect competition, equation (5) holds with  $\mu_i^i = 1$  at all times. In our second model (the "constant mark-up" model), it holds with  $\mu_i^i = \mu$ , a constant greater than 1, at all times. This corresponds to a model in which firms are monopolistic competitors, with the equilibrium mark up being determined by each firm's elasticity of demand, which in turn follows from the elasticity of substitution between the differentiated goods.<sup>8</sup>

Finally, in our third and most complicated model (the "variable mark-up" model), we assume that firms belong to oligopolies that maintain high prices through the threat of reversion to low prices if anyone devi-

<sup>8</sup> The assumption of a constant mark up at all times does not actually require an assumption that the individual firm's demand curve has a constant-elasticity form, as in the familiar model of Dixit and Stiglitz (1977). Given that we consider only the symmetric equilibrium, it suffices that the utility received from the differentiated goods be a homothetic function, so that the elasticity of substitution between different goods *along the symmetric-consumption income expansion path* is constant. See Rotemberg and Woodford (1991) for further discussion of this model.

ates. Rotemberg and Woodford (1992) show that this assumption implies that the mark-up  $\mu_i^j$  for each firm in industry  $j$  will be related to the ratio of expected future profits to current sales. In particular, the mark-up will be given by

$$\mu_i^j = \mu(X_i^j/Y_i^j), \quad (6)$$

where  $\mu(X/Y)$  is an increasing function,  $Y_i^j$  denotes the common output of each firm in the industry, and  $X_i^j$  denotes the expected present value of future profits gross of fixed costs for each firm in the industry, assuming that collusion is maintained. Higher expected future profits relative to current sales raise the expected losses from a breakdown of collusion relative to the potential gains from undercutting the other firms in one's industry at the present time. The result is that collusion is easier to sustain. The formal definition of  $X_i^j$  can be found in Rotemberg and Woodford (1991) where we explain how  $X$  depends on the possibility that oligopolies will either be dissolved or renegotiate their collusive arrangements.

We now describe the rest of our simulation model. To model the supply of labor and capital, we assume the existence of a representative household that seeks to maximize

$$E \left\{ \sum_{t=0}^{\infty} \beta^t U(A(C_t, E_t^h), H_t^s) \right\},$$

where  $\beta$  is a constant positive discount factor,  $C_t$  denotes consumption purchases of non-energy output (that for simplicity we treat here as entirely nondurable),  $E_t^h$  denotes household direct use of energy, and  $H_t^s$  denotes total hours worked (both for the private sector and for the government). The representative household is assumed to be a price taker in all markets, and to face the wage  $w_t$  for all hours supplied, and the after-tax price of  $p_E(1 + \tau_t)$  for energy. (In some of our simulations to follow, we allow the tax on direct household energy use to differ from the tax on energy inputs to production.) The household also accumulates the capital stock (the purchase price of which is the same as the price of consumption goods), and receives the rental rate  $r_t$  on its capital holdings; and it owns all firms and receives the profits from both non-energy and energy production. Capital holdings evolve according to

$$K_{t+1} = I_t + (1 - \delta)K_t,$$

where  $I_t$  are period  $t$  investment purchases of non-energy output, and  $0 < \delta \leq 1$  is a constant rate of depreciation.

In order to allow the existence of a balanced growth equilibrium in the case of a constant level of energy tax, we require certain homogeneity assumptions on household preferences as well. Specifically, we assume that the aggregator function  $A(C, E)$  for household expenditure is homogeneous degree one. We also assume that the utility function  $U(A, H)$  satisfies certain homogeneity assumptions explained further in Appendix 2. These imply that if the household is faced with a real wage that grows at a constant rate and a constant rate of return on savings, it will choose to supply a constant number of hours, and to consume a quantity that grows in proportion to the real wage.<sup>9</sup>

As noted above, we assume that the supply of energy is infinitely elastic so that the relative price at which energy is supplied is fixed exogenously, which is probably not strictly correct. However, the view that the elasticity of supply is large is justified to some extent by the fact the price of oil is determined in a world market in which the United States consumes only a quarter of world output.<sup>10</sup> Thus, even assuming that foreign demand is inelastic, the elasticity of supply faced by the United States is four times the world elasticity of supply. In addition, the foreign elasticity of demand also renders the effective supply of energy to the United States more price elastic. Put differently, any reduction in price brought about by a reduction in U.S. consumption would raise consumption elsewhere and thereby dampen the required fall in price. The result is that, even if the elasticity of the world supply of oil is zero, the effective elasticity of supply for the United States would equal three times the elasticity of demand of all the other nations. On the other hand, we abstract here from considerations of international trade by supposing that all U.S. energy usage (the sum  $E_i + E_i^h$ ) is supplied by firms that are owned by the same representative household referred to above.<sup>11</sup> We also ignore for simplicity the use of factor inputs in energy

<sup>9</sup> These assumptions are standard in the real business-cycle literature. See, for example, King, Plosser, and Rebelo (1988). Apart from their analytical convenience, in allowing us to analyze a steady-state balanced-growth path despite the existence of technical progress and endogenous labor supply, they are roughly accurate as a description of postwar U.S. growth. The most notable empirical embarrassment concerns not the growth of per capita private hours  $H_i$ , but the growth of per capita hours hired by the government, which exhibits a positive trend over the postwar period, contrary to the assumption of our model below. Needless to say, adequately dealing with the growth of the government sector observed over this period, if taken to represent a genuine long-run trend, would be incompatible with the existence of balanced growth.

<sup>10</sup> In 1989, the United States consumed 14.81 million barrels of oil a day while world production equaled 59.61 million barrels a day.

<sup>11</sup> We do assume in computing predicted changes in GDP that some of the energy is classified as "foreign" output for purposes of the national income accounts, but this is treated as an accounting convention with no economic significance. See equation (9) below.

production, and treat the revenues of the energy sector as pure rents (distributed as profits to the representative household).

We do take account of the consumption of real resources by the government, although in our simulations, government demand is assumed to grow deterministically with the rest of the economy. Specifically, we assume an exogenously given path for real government purchases of non-energy output  $G_t$ . In order to make possible a balanced growth path, we assume that  $G_t$  grows at the rate  $g$  of labor-augmenting technical progress. We similarly assume an exogenously given path for government purchases of people's time. In order to make possible a balanced-growth path of the kind already described, we assume that the hours per capita purchased by the government are a constant  $H^g$  at all times. We also assume that lump-sum taxes or transfers make up for any discrepancy in a given period between the value of government expenditure  $G_t + w_t H^g$  and the value of energy-tax revenues  $\tau_t(E_t + E_t^h)$ , which allows us to consider the effects of a change in the level of energy taxes while abstracting from the effects of changing other distorting taxes or of changing government expenditure patterns. Market clearing in the non-energy sector then requires that at each time

$$C_t + I_t + G_t = Y_t - M_t, \quad (7)$$

while market clearing in the labor market requires that

$$H_t + H_t^g = H_t^s. \quad (8)$$

In our numerical simulations, we consider the comparative dynamics associated with deterministic perturbations of the expected time path of the energy tax  $\tau_t$ . In the case of perturbations that are small enough, the effects are essentially linear in the percentage tax change. The magnitude of these linear effects can be obtained from a log-linear approximation to the equilibrium conditions of the model. We carry out this linearization around the long-run, steady-state, balanced-growth path to which the economy eventually converges and consequently state our results in terms of the percentage changes in non-energy output and so on *per percent increase in the energy tax*. Thus, the parameter values required in order to obtain numerical results are simply elasticities of the various functions introduced earlier and average values of the various quantities. The parameter values used in our simulations are listed in Table 2. The sources of these numerical values, as well as the interpretation of the parameters, are discussed further in Appendix 2.

In our basic simulation, we consider the effects of a permanent in-

TABLE 2.  
The Calibrated Parameters.

Parameter	Values	Description
$g$	0.030	Rate of technical progress (per year)
$r$	0.060	Steady-state real rate of return (per year)
$\delta$	0.073	Rate of depreciation of capital stock (per year)
$s_C$	0.697	Share of private consumption in final uses
$s_I$	0.186	Share of private investment in final uses
$s_G$	0.117	Share of government purchases in final uses
$s_E$	0.020	Share of energy costs in total costs
$s_M$	0.500	Share of materials costs in total costs
$s_H$	0.360	Share of labor costs in total costs
$s_K$	0.120	Share of capital costs in total costs
$s_{\phi}$	0, 0.1670	Share of fixed costs in total costs
$\theta^{dom}$	0.830	Share of domestically produced energy in total energy use
$\theta^h$	0.40	Share of direct household use in total energy use
$\eta^g$	0.170	Share of hours hired by the government
$\epsilon_{VG}$	0.690	Elasticity of substitution between value added and intermediate inputs
$\epsilon_{EM}$	0.180	Elasticity of substitution between energy and materials
$\epsilon_{KH}$	1.000	Elasticity of substitution between capital and hours
$1/\sigma$	0.500	Elasticity of intertemporal substitution of household expenditure
$\epsilon_{Hw}$	1.300	Intertemporal elasticity of labor supply
$\mu$	1, 1.200	Steady-state mark-up (ratio of price to marginal cost)
$\epsilon_{\mu}$	0, 0.150	Elasticity of the mark-up with respect to $X/Y$
$\alpha$	0.900	Expected rate of growth of individual oligopoly's expenditure share
$\rho$	0.200	Rate of partial adjustment of number of firms

crease in the energy tax  $\tau$  that is announced (unexpectedly) at the same time that it takes effect. We assume the economy to have previously converged to the steady-state balanced-growth path associated with the previous level of the energy tax (zero), and consider the path by which it converges to a new, long-run steady state following the change. We also consider, for purposes of comparison, an experiment in which only the tax rate on direct household use of energy is increased, with no change in the tax on uses of energy as an input to non-energy production. In this case, the relative price of energy inputs in production continues to be  $p_E$ , while the relative price of energy for household use becomes  $p_E(1 + \tau)$ . This comparison is of interest because the gasoline tax that eventually was passed as part of the 1994 budget is, effectively, a tax that falls disproportionately on the energy purchased by households. It is thus of interest to compare the effect of such a tax to those more broad-based,



**TABLE 3.**  
*Long-Run Effects of an Energy Tax.*

	Tax on all energy use		Household use only	
	<i>Competitive</i>	<i>Market Power</i>	<i>Competitive</i>	<i>Market Power</i>
Non-energy output	-0.071	-0.097	0	0
GDP	-0.072	-0.098	-0.022	-0.022
Hours worked	-0.024	-0.021	0	0
Product wage	-0.056	-0.085	0	0
Consumption wage	-0.092	-0.122	-0.037	-0.037
Energy use in production	-0.271	-0.297	0	0
Household energy	-1.052	-1.082	-1.000	-1.000
Capital stock	-0.084	-0.110	0	0
Number of firms	—	-0.033	—	0

such as the Btu tax originally proposed by President Clinton. As might be expected, we will demonstrate that imperfect competition increases the output losses associated with an energy tax *only* in the case of a tax on the use of energy in production. The reason is that imperfect competition affects the degree to which output falls only by affecting the energy purchases of firms.

## 5. LONG-RUN EFFECTS OF A PERMANENT ENERGY TAX

Table 3 summarizes the changes in the long-run levels of several variables for each of four cases. The two types of tax changes considered are a shift from zero energy tax to a 1 percent tax on all energy use (first two columns)<sup>12</sup> and a shift from no energy tax to a 1 percent tax on the direct use of energy by households (last two columns), assuming no tax on industrial uses of energy. Each tax change is considered for two alternative assumptions about product market structure. In the "competitive" case (left column of each pair), we assume perfect competition (i.e.,  $\mu = 1$ ). In the "market power" case (right column of each pair), we assume imperfectly competitive product markets, with the typical firm possessing market power sufficient to lead it to set prices 20 percent higher than its marginal cost of production in the steady-state equilibrium (i.e.,  $\mu = 1.2$ ).

<sup>12</sup> Although we assume here an initial steady state with no energy tax, the results would be similar in the case of a 1 percent increase in the value of  $(1 + \tau)$ , starting from a positive initial tax.

As noted above, our specification of a value for the steady-state mark-up  $\mu$  also determines our specification of the degree of increasing returns in the production technology. In the "competitive" case, we assume constant returns to scale ( $\Phi = 0$ ). In the "market power" case, we assume the existence of increasing returns due to the presence of fixed costs ( $\Phi > 0$ ) and endogenous determination of the number of firms (and hence varieties of differentiated goods). Thus, in this case there exist increasing returns such that average cost is 20 percent higher than marginal cost for the typical firm in the steady-state equilibrium. In the two cases, all other parameters are calibrated in the same way.

One issue that arises at this point is whether a mark-up of 1.2 is reasonable. There are essentially two sources of information on this parameter. The first stems from the abundant literature that attempts to measure the elasticity of demand facing individual products produced by particular firms. This literature is relevant because it is never profit maximizing for a firm to set its mark-up lower than one over one plus the inverse of the elasticity of demand for its product. There are many estimates of the elasticity of demand for particular products in the marketing literature. Tellis (1988) surveys this literature and reports that the median, measured price elasticity is just under 2. Thus the mark-up would equal at least 2 if this sample of firms is representative. In practice, elasticities of demand undoubtedly differ across products, and the elasticity of demand of those products studied in the marketing literature is probably atypically low, because the marketing literature focuses on the demand for branded consumer products, which are more differentiated than unbranded products and probably have a less price sensitive demand curve. Thus, the typical product in the economy probably has a price elasticity of demand that exceeds 2.

A second approach is to analyze what happens to revenue and costs in response to an exogenous change in aggregate demand. A particularly simple version of this approach has been proposed by Hall (1988, 1990). He studies the degree to which the increase in GDP generated by increases in exogenous variables, such as changes in military purchases, is accompanied by an increase in costs. Insofar as GDP increases by more than costs, the mark-up is greater than one. His estimates indicate that the mark-up  $\mu$  is between 1.4 and 1.6.<sup>13</sup>

There is also a related literature that tries to obtain econometric esti-

<sup>13</sup> His reported estimates for mark-ups are actually even higher because he estimates "value added" mark-ups as opposed to the more standard mark-ups of price over total marginal cost. For a discussion of the relation between the two, see Rotemberg and Woodford (1992).

mates of marginal cost and in some cases combine them with econometric estimates of the elasticity of demand. The aim of this approach is to obtain simultaneous, independent estimates of the mark-up and of the degree of increasing returns. Morrison (1990), for example, estimates a flexible, functional-form cost function, using data on gross industry output and materials inputs. Her estimates of that mark-up  $\mu$  range between 1.2 and 1.4 for sixteen out of her eighteen industries. Notably, her estimates of the ratio of average to marginal cost closely resemble her estimates of the mark-up itself. Thus, the relation between these two parameters that we imposed through our zero-profit condition appears to be validated.

Because we are considering only long-run effects, the results do not depend on whether the tax increase is immediate or phased in over a period of time; only the eventual permanent increase in the tax rate matters. Similarly, the results do not hinge on whether the long-run substitutability of factors of production exceeds their short-run substitutability; only the long-run substitution possibilities matter here.

Furthermore, the "market power" case reported in Table 3 refers equally to the monopolistically competitive model and to the oligopolistic collusion model. The reason is that in neither case does the energy tax change have any effect on the mark-up of prices over marginal cost in the long-run steady state. In the case of monopolistic competition, the mark-up is predicted to be a constant, determined solely by the elasticity of substitution between alternative differentiated goods. In the oligopolistic model, by contrast, the mark-up depends upon the ratio  $X/Y$  and so can vary in response to policy changes. However, in a steady-state equilibrium, the present discounted value of profits  $X$  is proportional to  $Y$ . Moreover, though the steady state value of  $X$  also depends on the steady-state real rate of interest,  $r$ , this real rate of interest is determined solely by preference parameters and the exogenous rate of growth (see Appendix 2). Hence the steady-state  $r$  is unaffected by the energy tax, and as a result steady-state  $\mu$  is also unaffected. Thus the long-run effects are the same in either type of imperfectly competitive model; all that matters is the size of the steady-state mark-up  $\mu$ .

We now turn to the numerical results reported in Table 3. In each row, the figure reported represents the *percentage change* in the long-run value of that variable, resulting from a 1 percent energy tax. (In our log-linear approximation to the equilibrium, the effects of a  $k$  percent energy tax are obtained by multiplying each of these numbers by  $k$ .) The variables, of course, grow over time in the steady-state equilibrium; but the steady-state growth rate is unaffected by the energy tax (as it is determined solely by the exogenous rate of technical progress). Thus the figure

-.071 for non-energy output means that output is -.071 percent lower at all times than it otherwise would have been in the new, long-run steady-state growth path. "Non-energy output" refers to the gross output  $Y_t$  of the energy-using (but not energy-producing) sector. The change in "GDP" is computed as

$$\Delta Y_t - \Delta M_t - p_E \Delta E_t + \theta^{dom} p_E (\Delta E_t + \Delta E_t^h), \quad (9)$$

where  $\Delta$  indicates the difference (*not* percentage difference) in value of the equilibria between the perturbed and unperturbed equilibria, and  $\theta^{dom}$  denotes the share of energy used in the United States that is domestically produced.<sup>14</sup> Thus the GDP measure aggregates value added in the non-energy sector and the domestic energy-producing sector, in which for simplicity the total revenues of the latter sector are counted as value added. "Hours worked" denotes total hours worked  $H_t$ ; because government hours are assumed to follow an exogenous path unaffected by the energy tax, the reported decline in hours is only 83 percent of the size of the decline in hours in the private non-energy sector. The "product wage" refers to the wage deflated by the price of non-energy input and the "consumption wage" refers to the wage deflated instead by the price index  $p_{A_t}$  of the household consumption basket,

$$p_{A_t} \equiv \frac{C_t + p_E(1 + \tau_t)E_t^h}{A(C_t, E_t^h)}. \quad (10)$$

"Energy use in production," "capital stock," and "number of firms" refer to the variables  $E_t$ ,  $K_t$ , and  $N_t$  introduced in the previous section; all refer solely to the private non-energy sector. The number of firms is indeterminate in the competitive model.

A striking feature of the results in Table 3 is that a tax levied only on direct household purchases of energy has *no effect whatsoever* on equilibrium activity in the private non-energy sector. Household energy use falls, and the consumption wage falls because the price index  $p_A$  rises. However, the household does not change its supply of labor or demand for non-energy goods; nor does the equilibrium product wage in the non-energy sector change. GDP falls only because of the reduction in domestic energy production due to reduced household use of energy.<sup>15</sup>

<sup>14</sup> Implicitly, we assume here that U.S. energy production varies in the same proportion as U.S. energy use.

<sup>15</sup> Goulder (1993b) also reports smaller losses in GDP for taxes that affect only the household's use of energy.

Two features of our model account for this result. The first is that we made assumptions that ensured the existence of a steady state in which the economy grows but hours worked do not. Because output, consumption, energy purchases, and wages all grow at the same rate in such a steady state, we require that equiproportional increases in wages and the aggregate  $A_t = A(C_t, E_t^h)$  be consistent with an unchanged quantity of labor supplied.<sup>16</sup> A permanent increase in the tax on household energy raises  $p_E(1 + \tau_t)$  and thus raises the consumption deflator  $p_{A_t}$  while it lowers the consumption wage. As long as  $A_t$  falls in exact proportion to the increase in  $p_{A_t}$  and the product wage is unaffected, the fall in the real wage and in consumption remain equiproportional, and the quantity of labor supplied does not change.

The second important source of this result is our assumption that the household's elasticity of substitution between non-energy consumption and direct energy use is equal to 1. We base this assumption on the unit elasticity of demand estimates of Houthakker, Verleger, and Sheehan (1974). What it means is that the shares of household expenditure on energy and non-energy output will remain constant in the face of a change in the relative price of these two kinds of goods. But suppose that the path of  $p_{A_t}A_t$  is unchanged under the circumstances just described; it then follows that the paths of  $C_t$  and of  $p_E(1 + \tau_t)E_t^h$  are unchanged. Thus, household energy use falls in inverse proportion to the tax increase, through non-energy consumption demand and labor supply are unchanged. It follows that if the product wage and the real rate of return are unaffected, consumption demand and labor supply are unchanged, and output in the non-energy sector can remain constant as well, implying in turn that the previous paths of the product wage and the real rate of interest continue to describe an equilibrium. This argument applies with or without perfect competition because the two models differ only in the way non-energy firms react to changes in their environment. But, as we just saw, a tax on household use of energy does not affect this environment.

Since the tax on household direct use of energy has no effect on non-energy output, the output effects of a tax on all energy are due to the tax on the industrial use of energy. The effects would have been just as large if *only* the energy used in production were taxed. It is true that the zero effect of the tax on direct household use depends upon particular parameter choices that might well be challenged. However, for any values near ours, the result will be approximately the same—the effects of a tax

<sup>16</sup> To obtain this result we assume that the Frisch consumption demand curve and the Frisch labor supply curve satisfy certain homogeneity properties explained in Appendix 2.

on household energy use will be much smaller than the effects of a tax on industrial uses, and indeed the effects of a tax on household energy use could as easily be expansionary as contractionary. Thus, the shift from a Btu tax to a gasoline tax in the budget that eventually was passed by Congress probably resulted in less of a burden on the economy, per dollar of revenue raised. Another implication about designing a tax intended to reduce carbon dioxide emissions is that a tax directly mainly at household energy use is likely to contract economic activity less, for any given reduction in emissions that is achieved, than one based simply on the "carbon content" of various fuels.

Now consider the effects of a tax on all types of energy use. Private non-energy production contracts, as do hours worked, the energy used in production, the capital stock, and the real wage deflated by the price of non-energy output. The contraction in hours stands in contrast to the case of a tax on energy consumption only. It comes about because a tax on all energy lowers the consumption wage by more than it lowers  $A_t$ . Table 3 shows that in this case GDP falls by slightly more than does non-energy output. The reason is that the contraction of the energy sector is even more severe, in percentage terms, than the contraction of the private non-energy sector. In the imperfectly competitive case, there is also a reduction in the long-run number of firms, due to exit in response to profits no longer large enough to cover the fixed costs.

Even in the competitive case, the output lost as a result of the energy tax is rather significant. Because the share of total energy expenditure in GDP is 0.066, a 1 percent tax increase raises government revenues by only 0.066 percent of GDP. On the other hand, GDP is itself reduced (in the long run) by 0.071 percent.<sup>17</sup> The ratio of output loss to revenue raised is even more severe if one considers a pure tax on industrial uses of energy. In this case, a 1 percent energy tax raises government revenues by only 0.040 percent of GDP, while GDP is reduced by 0.050 percent.<sup>18</sup>

<sup>17</sup> This ratio of the output loss to the revenue raised is comparable to what is implied by the results of other authors. For example, Goulder (1992) estimates that a \$25 (in 1990 prices) per ton tax on carbon content will reduce real GNP in 2020 by an amount that varies between 0.76 percent and 1.14 percent, depending upon the structure of the tax (see his Table 7). Using the figures in his Table 1 on the percentage that this corresponds to for different types of fuel, one finds that this corresponds to an average tax rate on energy use of 14.5 percent, so that the revenues raised should be only approximately 0.96 percent of GNP, even ignoring the reductions in the cost share of energy that should follow from such a severe tax. Goulder (1993b), on the other hand, reports smaller GNP losses. He considers a tax of \$0.45 per million Btu's which corresponds roughly to a 22 percent tax on energy and computes a reduction in GNP of only 0.33 percent. By contrast our estimates imply that a 22 percent tax would lead to GDP losses of 1.5 percent.

<sup>18</sup> Non-energy output still falls by 0.071 percent in this case, but the energy sector contracts to a much smaller extent. Total energy sales are affected more by a tax on household

But the contractionary effects of an energy tax are even greater when one allows for imperfect competition. In the case of market power, the long-run decline in non-energy output is 0.097 percent, and the long-run decline in GDP is 0.098 percent. Thus even a relatively modest degree of market power (prices 20 percent above marginal cost) significantly increases the predicted effect of the energy tax; the long-run, non-energy output decline is increased by a factor of nearly 1.4.

The reason can be understood by analyzing equation (5) in the same way that we analyzed equation (2) in Section 3. It follows from (5) that a value  $\mu > 1$  implies a higher estimate of the elasticity of the aggregator  $Q$  with respect to  $G$ . From the shares reported in Table 2, the implied value of this elasticity is increased from 0.52 to 0.624 (a factor of 1.2) by raising  $\mu$  to 1.2. The elasticity of  $Q$  with respect to  $V$  similarly falls from 0.48 to 0.376. Furthermore, as in Section 3 the higher value of  $\mu$  implies that the fall in  $G$  is larger in response to a change in the price  $p_G$ . It turns out that, for fixed  $V$ , the fall in  $G$  is inversely proportional to the elasticity of  $Q$  with respect to  $V$  and thus is larger by a factor of 1.28 when  $\mu = 1.2$ . If the index of primary inputs  $V$  were not affected by the energy tax,  $G$  would have to fall by 1.28 times as much, and so output would fall by 1.53 ( $= 1.2 \times 1.28$ ) times as much, in the case of market power. In fact, the difference between the output declines in the two cases is not so extreme in our simulations because  $V$  actually falls more in the long run in the competitive case. Nonetheless, the contraction is significantly larger in the presence of market power.

The energy tax also has significantly greater adverse effects in the case of market power in several other respects as well. For example, the real product wage falls by more than 1.5 times as much in percentage terms. This indicates a more significant contraction of labor demand; the only reason that hours worked do not fall more is that households are willing to accept the lower real wage because of their lower wealth in this case.

## 6. SHORT-RUN EFFECTS OF CHANGES IN TAX POLICY

In this section we begin the more complex analysis of the short-run effects of changes in policy. We focus here on the transition to a new, long-run steady state consistent with a new permanent tax rate. During this transition the effects of tax-rate changes differ depending on

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energy use than by a tax on industrial uses, because our calibration implies that energy is more substitutable for other goods for households than for firms.

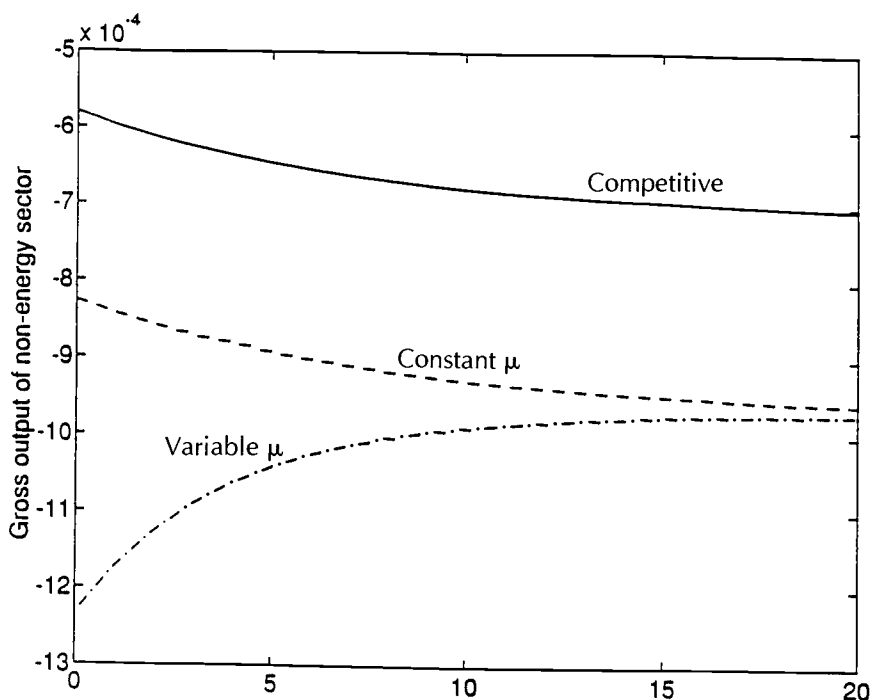


FIGURE 2. *Effect of Immediate, Permanent Energy Tax Increase.*

whether mark-ups are constant or not. We thus consider our two models of imperfect competition separately.

We consider here an unexpected permanent increase in the energy tax rate  $\tau$  from zero to 0.01 that takes effect immediately. Because the tax change is not anticipated in advance, we suppose the economy starts out in the steady-state balanced-growth path associated with zero energy taxation. We imagine that the tax applies to all uses of energy, although as explained in the previous section, the effects of the tax on the non-energy sector follow solely from the taxation of energy used as an input to non-energy production.<sup>19</sup>

Figure 2 displays the transitional effects on non-energy output, under the three alternative specifications of product market structure. The vertical axis indicates percentage deviations from the previous steady-state

<sup>19</sup> The argument just made shows that in the case of an immediate, permanent tax on direct household energy use only, the economy will immediately jump to a new steady-state balanced-growth path described in Table 3. Thus, there is no effect on non-energy output, consumption, and so on, in either the short run or the long run.



growth path;  $-10 \times 10^{-4}$  means a reduction of 0.10 percent. The horizontal axis indicates the year; year 0 is when the tax change is announced and takes effect. In the competitive case, the tax lowers non-energy output by 0.071 percent in the long run, as we showed in Table 3. We now see the short-run effects as well. In the first year, non-energy output is already reduced by 0.058 percent. In subsequent years, output continues to fall further below the previous trend path, as the capital stock is eroded; but a large part of the eventual output decline occurs immediately. In the case of the constant mark-up model, the general picture is similar. But, as the elasticity of output with respect to energy inputs is larger in this case, the decline in output is larger both in the short run and in the long run.

In the case of the variable mark-up model, the long-run effects are the same as for the constant mark-up model. As explained in the previous section, both models predict a long-run reduction of non-energy output by 0.097 percent. However, the short-run effects are quite different. During the first year of the energy tax the constant mark-up model predicts a reduction by 0.083 percent, while the variable mark-up model predicts a reduction by 0.123 percent. The predicted short-run effect is almost one-and-one-half times as large (hence more than twice the size of the effect in the competitive model), because the variable mark-up model predicts that the mark-up increases when the energy tax is increased and then gradually returns to its original level over time. The mark-up increases because the ratio  $x/y$  increases. This situation occurs, in the first instance, because of a decline in real interest rates that results from the reduced returns to capital (which eventually return to normal as the capital stock is reduced). Lower real interest rates mean that the expected future profits from collusion are discounted to a lesser extent, making a greater degree of collusion possible. Higher mark-ups then themselves contribute to a higher ratio of profits to sales each period, making  $X/Y$  still higher and so helping to raise mark-ups further. Higher mark-ups also further reduce the returns to existing capital goods, thus lowering real rates of return, raising  $X/Y$ , and further raising mark-ups in a self-reinforcing process.

In our simulation, the mark-up increases by 0.011 percent during the first year of the tax (i.e., from 1.2000 to 1.2001). Even this small increase in the inefficiency wedge due to firms' market power has a significant effect on the predicted equilibrium allocation of resources. To understand why, it is helpful to suppose first that labor supply is inelastic. Then,  $V_t$  is entirely predetermined. As a result, equation (5) determines  $G_t$  as a function of  $(\tau_t, \mu_t)$ . Then, using equation (3),  $Y_t$  depends only on  $(\tau_t, \mu_t)$ . Now let us investigate for a given increase in  $\tau_t$  the quantitative

effect of an increase in  $\mu_i$ . Because energy costs are only about 4 percent of total intermediate input costs, a 1 percent increase in the after-tax energy price raises the price index  $p_{G_i}$  by only 0.04 percent. Thus a contemporaneous 0.011 percent increase in the mark-up means that the right-hand side of (5) increases by 1.3 times as much (in percentage terms) as it would in the case of a constant mark-up. In our log-linear approximation to the solution, the percentage decline in  $Y_i$  is proportional to the percentage increase in the right-hand side of (5), and so it should be 1.3 times as large in the variable mark-up case.

In our simulation model, we also allow for endogenous labor supply.<sup>20</sup> In this case, households reduce labor supply rather than accept a real-wage cut of the size that would be required to induce firms not to reduce the labor inputs that they use. Thus, non-energy output falls even more than it would in the case of inelastic labor supply. This effect is present regardless of product market structure. However, one can easily see that the real wage decline required to induce firms not to reduce labor inputs is larger if the mark-up rises. For it follows from (5) that if the mark-up rises, the value of  $G_i$  falls more, and hence that  $Q_V(V_i, G_i)$  for fixed labor and capital inputs falls more. On the other hand, the same logic that leads to (5) implies that the real wage must equal  $Q_V V_H / \mu$ . The fall in the real wage is thus magnified both by the increase in  $\mu$  and by the severity in the fall of  $Q_V$ . Thus, it makes sense that in the case of endogenous labor supply, the effect of the mark-up increase on output is even greater. The fact that such small changes in the mark-up can matter so much for the size of the predicted effects of the tax increase leads us to insist on the importance of product market structure for tax analyses of this kind.

## 7. THE EFFECT OF EXPECTED CHANGES IN ENERGY TAXES

Up to this point we have considered the effect of unanticipated permanent increases in energy taxes. There are several reasons, however, for energy taxes to be anticipated. First, there is a time gap between the moment when tax policy is announced and when it takes effect. In particular, the Clinton proposal called for a gradual phase-in of the Btu tax. Second, tax changes are not necessarily permanent. Any particular

<sup>20</sup> Note that it is not essential to our conclusions that this variation in labor supply be interpreted as "voluntary." Qualitatively similar conclusions would be obtained in the case of any source of short-run "real wage rigidity," due for example to pre-existing wage contracts or to efficiency-wage considerations.

tax, such as the energy tax has some probability of being repealed in the future.

We start by considering the case of gradual phase-in and report simulations in which the energy tax is increased by 0.5 percent in the year that it is announced, and the full 1 percent tax applies from the second year onward. The comparison with the case of an instantaneous increase in the tax is interesting in part because a gradual phase-in was actually proposed. Moreover, as we will show, the effect of this gradual phase-in depends even more crucially on product market structure than the eventual effect of a permanent tax.

The consequences for non-energy output are shown in Figure 3 for each of the possible market structures. As one might expect, output falls by less in the first year than if the full tax were to take immediate effect. In fact, in none of the models is the contraction in the first year even half the size indicated in Figure 1. In the case of the competitive model, the first-year decline in non-energy output is only 0.016 percent; in the

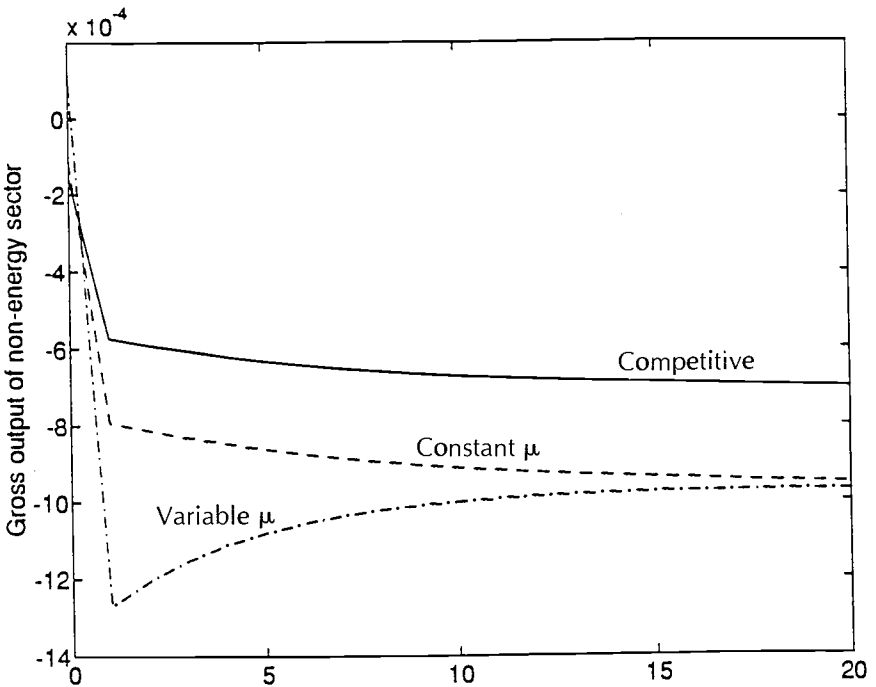


FIGURE 3. Energy Tax Increase: Gradual Implementation.

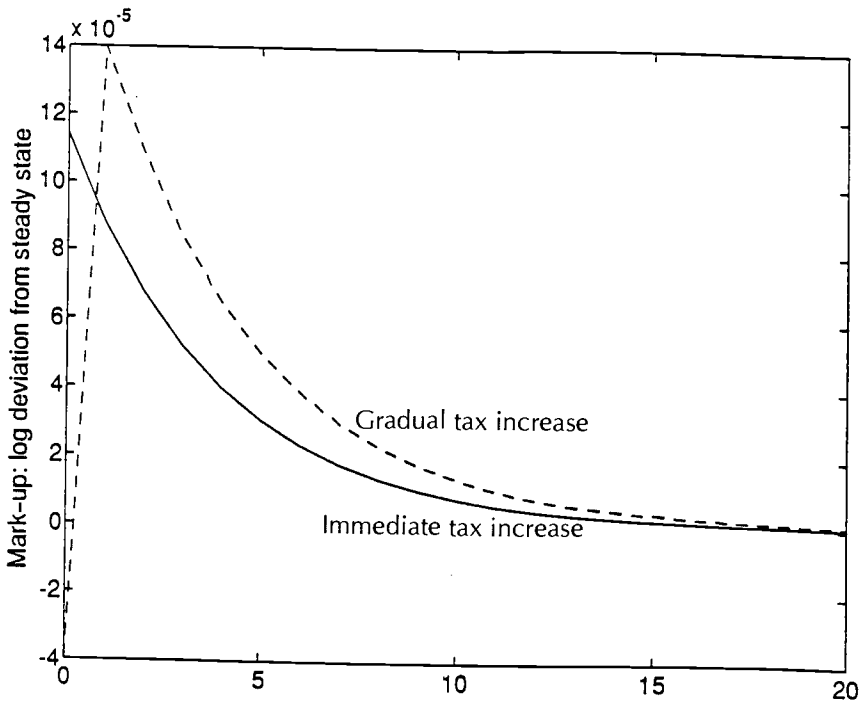


FIGURE 4. Dynamics of Mark-Up in Variable  $\mu$ .

constant mark-up model, it is only 0.012 percent; and in the variable markup model, output does not decline at all in the first year, but instead rises by 0.011 percent.

One reason for the first year effect to be so muted is that the wealth effect on labor supply, which tends to increase equilibrium output, is nearly as large in these simulations as in the previous ones. On the other hand, the current increase in energy costs, which tends to reduce equilibrium output, is only half as large. The other important factor, in the case of the variable mark-up model, is that expectations of future profits are reduced nearly as much as in the previous simulations, whereas current sales are reduced by much less. Consequently, the ratio  $X/Y$  falls, and so the equilibrium mark-up is temporarily reduced in the oligopolistic model. The path of the equilibrium mark-up in the oligopolistic model is shown in Figure 4 for the cases of the immediately effective tax and the phase-in over a one-year period. In the case of the gradual phase-in, the mark-up falls by about 0.004 percent (i.e., from 1.2 to 1.9995).

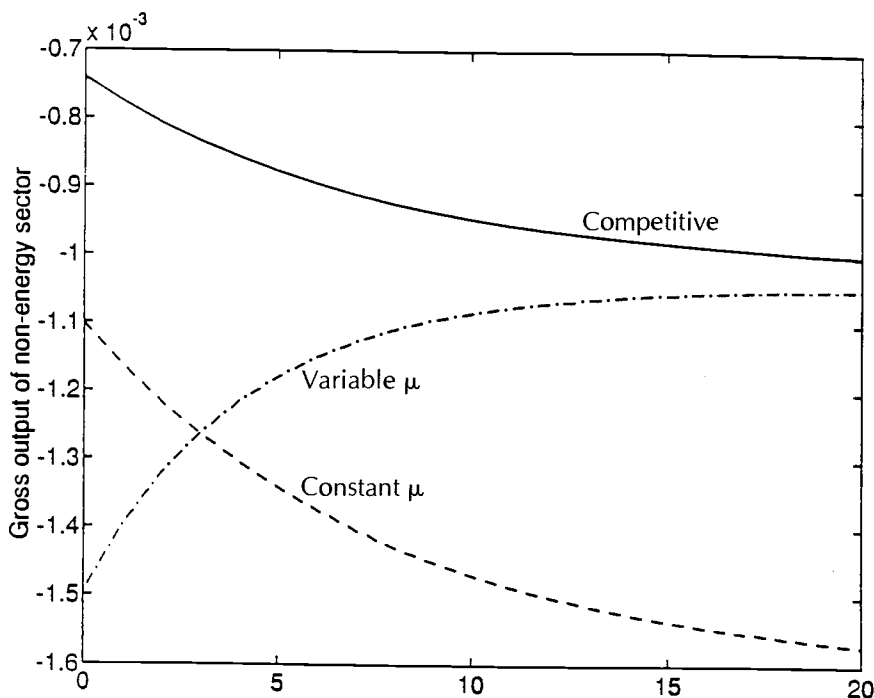
After the first year, the path of output in these simulations is similar to

the one we derived for an immediate tax increase. The only difference is that the higher output in year 0 is associated with a higher level of investment. Thus, the capital stock in year 1 is higher. In fact, the economy now begins year 1 with a slightly larger capital stock than in the original balanced-growth path in all cases. By contrast, the capital stock was slightly lower in each of our previous simulations. In the case of the competitive model and the constant mark-up model, the higher capital stock means that the output decline in year 1 and later is not quite as large as in the previous simulations. On the other hand, in the case of the variable mark-up model, we find that a higher capital stock actually makes the output decline even more severe. The higher capital stock implies that real interest rates are even lower, which implies that  $X/Y$  is even higher and thus leads to even higher mark-ups. Figure 4 shows that, indeed, the mark-ups in year 1 and later are actually greater in the case of a phased-in tax.

Finally, we report simulations in which the tax increase is not expected to be permanent. We now suppose that the tax is increased to 1 percent on all uses of energy, but that it is anticipated that each year there is a 20% probability that the tax rate will be permanently restored to its original value. In our dynamic equilibrium model, the effects of a tax increase cannot be analyzed independently of expectations about future policy, and it is important to realize that economic agents need not expect that a tax change is permanent simply because the bill that is enacted does not specify a future date at which it becomes invalid. Here too we find that the effects of an expectation of future policy reversal depend greatly on our assumptions about product market structure.

Figure 5 presents the time path of non-energy output in the case of the three possible market structures. What is plotted is the level of non-energy output for each year relative to the previous trend growth path, assuming no reversal of the tax up until that time. In the case of both the competitive model and the constant mark-up model, the contraction of non-energy output is greater than it would have been were the tax expected to continue forever. This situation is due to the wealth effect on labor supply; optimism about reversal of the tax makes households expect higher future incomes and thus makes them less willing to work in the present. Hence, the contractionary effects of energy taxes may, in practice, be considerably greater than those indicated in Figure 1.<sup>21</sup>

<sup>21</sup> There are other reasons why one might expect the stimulus to labor supply from the expectation of low future incomes not to be as large as in the simulations depicted in Figure 1. For example, one might suppose that some suppliers of labor are unable to borrow against future income in any event. In such a case, the contractionary effects of an energy tax are likely to be larger than those indicated in those simulations.



**FIGURE 5.** Tax Increase with 20 Percent Chance of Reversal Each Period.

In the case of the variable mark-up model, things are more complex. Again, the expectation of a possible reversal lowers first-period output because of the wealth effect on labor supply. However, the possibility of a policy reversal also raises the equilibrium real rate of return, because higher rental rates on capital are expected in the event of the tax's repeal. This higher rate of return lowers the present discounted value of future profits relative to current revenues. The resulting reduction in  $X/Y$  lowers equilibrium mark-up in the oligopolistic model. Though the mark-up still rises following enactment of the tax, it does not rise as much as in the simulation depicted in Figure 1. And, assuming that the tax has not yet been repealed, the equilibrium mark-up from year 3 onward in the oligopolistic model is actually lower than that in the monopolistically competitive model. This situation occurs because, once the capital stock has fallen sufficiently below its initial level, the real rate of return remains consistently above the real rate associated with the initial steady state. The consequence is that if, contrary to expectation, the tax contin-

ues for many years, output is actually higher in the oligopolistic model than in the monopolistically competitive model.

## 8. CONCLUSIONS

We have found that allowing for imperfect competition in product markets has an important quantitative effect on estimates of the effects of energy taxes on the level of economic activity. Allowing for even a modest average mark-up of prices over marginal cost increases the predicted decline in output that is caused by an increase in the after-tax relative price of energy inputs. And allowing for even a small increase in equilibrium mark-ups, due to increased sustainability of collusion among members of an oligopoly, can greatly increase the predicted output decline.

We have paid particular attention to a specific model of oligopolistic collusion that we have elsewhere argued helps to explain the responses of the U.S. economy to a variety of macroeconomic shocks. This model implies that an increase in energy taxes may well raise equilibrium mark-ups temporarily, especially when the tax increase is expected to be reserved soon with significant probability. In this case, the short-run contradictory impact of an energy tax is especially large. This effect is, however, sensitive to the precise dynamic specification of the proposed taxes. Mark-ups in the oligopolistic model may fall rather than rise immediately following announcement of an energy tax increase if there is a delay in the implementation of the tax.

In general, our results suggest an even less favorable relation between the revenues raised by an energy tax and the reduction of economic activity than earlier studies (assuming competitive markets) have indicated. For example, in the case of immediate implementation of a 1 percent energy tax that is expected to be reversed each year with a 20 percent probability, the revenues raised in the first year of the tax will be 0.066 percent of GDP, while GDP is itself reduced by 0.110 percent in the first year according to the constant mark-up model, and by 0.142 percent according to the variable mark-up model. The GDP reduction five years later is only 0.098 percent in the variable mark-up model if, contrary to expectation, the tax increase has not yet been reversed; but it is by that time 0.134 percent in the constant mark-up model. Although we do not here analyze alternative revenue sources, we believe that an energy tax is relatively unattractive on this dimension.

Our results also suggest ways in which an energy tax might be structured to minimize the contractionary effects. Our most important finding in this respect is that a tax solely on direct household use of energy need not contract non-energy production at all. Insofar as allowing for

imperfect competition increases the predicted contractionary effects of a tax on industrial uses of energy, but does not affect the predicted consequences of a tax on direct household use, it makes the case for targeting household energy use even stronger.

The short-run contractionary impact of an energy tax is also reduced if the tax is phased in gradually, and our simulations indicate that the output gained in the transition period is much larger than the revenue losses due to the gradual phase-in. In the case that we analyze here, for example, gradual phase-in involves a revenue loss of 0.033 percent of GDP in the first year relative to the revenues from immediate implementation. But the result is that GDP falls by 0.070 percent less in the case of constant mark-ups equal to 1.2, and by 0.109 percent less in the case of the variable mark-up model. In the case of the constant mark-up model, the output loss is also somewhat mitigated in later years, although it is made slightly worse in the case of the variable mark-up model.

## APPENDIX 1: ENTRY AND THE ELIMINATION OF PROFITS

We have stated above that in the long run, entry and exit are assumed to maintain pure profits at zero. It is straightforward to show that the first-order conditions for profit maximization imply that pure profits are zero in a symmetric equilibrium if and only if

$$(\mu_t - 1)Y_t = Q_v(V_t, G(E_t, M_t))N_t\Phi, \tag{A-1}$$

where  $\mu_t$  denotes the common mark-up of all firms. Equation (A-1) would thus determine the equilibrium number of firms each period in the case of instantaneous entry and exit. This equation refers only to the case of imperfect competition and increasing returns where  $\mu$  exceeds one and  $\Phi$  is strictly positive. Otherwise, as usual with constant returns, the number of firms is indeterminate.

We do not, however, suppose that entry and exit occur so quickly. Because entry and exit are peripheral to our main interests here (and because, as long as they are slow, the exact dynamics do not matter much for our results) we adopt a simple ad hoc specification rather than explicitly model the entry and exit decisions. Let us define

$$\bar{N}_t \equiv \Phi^{-1} \lim_{k \rightarrow \infty} (1 + g)^{-k} E_t \left\{ \frac{(\mu_{t+k} - 1)Y_{t+k}}{Q_v(V_{t+k}, G(E_{t+k}, M_{t+k}))} \right\}. \tag{A-2}$$



Thus  $\bar{N}_t$  denotes the number of firms needed at date  $t$ , if a constant rate of growth  $g$  of the number of firms ever after is to result in zero profits in the long run. We then assume that the number of firms grows exogenously at the rate  $g$ , except for a slow tendency to correct any discrepancy between the current number of firms and  $\bar{N}_t$ . Specifically, we assume dynamics for the number of firms given by

$$N_t = \rho \bar{N}_t + (1 - \rho)(1 + g)N_{t-1}, \quad (\text{A-3})$$

where  $0 < \rho \leq 1$  is a constant partial-adjustment rate. This specification introduces an additional predetermined state variable, in addition to the aggregate capital stock  $K_t$ , and that is the previous number of firms  $N_{t-1}$ . Note that once there ceases to be new information about future policy,  $\bar{N}_t$  grows at the constant rate  $g$ , so that (A-3) implies that the percentage discrepancy between  $N_t$  and  $\bar{N}_t$  is eliminated at an exponential rate. Substitution of (A-2) and comparison with (A-1) indicates then that the share of pure profits in total revenues must asymptotically approach zero, as desired.

## APPENDIX 2: PARAMETER VALUES USED IN SIMULATIONS

Here we explain the numerical values reported in Table 1. The steady-state balanced-growth path of the economy is described by a set of growth rates and shares that we calibrate using the U.S. national income accounts. According to our model, the exogenous rate  $g$  of labor-augmenting technical progress is also the steady-state rate of growth of real GDP, which is why we assign the value 0.03 / year. The parameter  $r$  represents the real rate of return in the steady-state equilibrium. This parameter is not a primitive of the model, but the model predicts that it should equal  $\beta^{-1}(1 + g)^{\sigma}$ , so that calibration of  $r$  is equivalent to calibration of the rate of time preference of the representative household. Following King, Plosser, and Rebelo (1988), we calibrate  $r$  to match the average real return on the U.S. stock market. The parameter  $\delta$  represents the exogenous rate of depreciation of the capital stock of the private non-energy sector. The model implies that in a steady-state equilibrium, the share of investment in final uses and the share of capital in total costs must be linked, through the relation

$$\frac{s_I}{g + \delta} = \frac{s_K}{(r + \delta)(1 - s_M)}. \quad (\text{A-4})$$

Hence, the values assumed for  $g$  and  $r$ , and the share parameters discussed below, imply a value for  $\delta$ , which is the one given. These parameters imply a steady-state capital-output ratio in the private non-energy sector of 7.5 quarters, which is reasonably consistent with the national income accounts as well.

The parameters  $s_C$ ,  $s_I$ ,  $s_G$  represent the steady-state shares of private consumption expenditure, private investment expenditure, and government purchases of private non-energy output, respectively, in total final uses  $Y - M$  of private non-energy output. We calibrate these shares to equal the average shares of these three kinds of expenditure in U.S. private value added (GDP minus value added by the federal, state, and local governments). The parameters  $s_E$ ,  $s_M$ ,  $s_H$ ,  $s_K$  represent the steady-state shares of energy, materials, labor, and capital costs, respectively, in the total costs of the private non-energy sector.

As we explained in Section 2, energy costs in the non-energy sector are 4.2 percent of value added. Hence we must have

$$\frac{s_E}{1 - s_E - s_M} = 0.042. \tag{A-5}$$

We assume, somewhat arbitrarily, a share of materials costs of 0.5, which is somewhat smaller than the average materials share indicated in the Commerce Department data for U.S. manufacturing sectors, but we suppose that materials are a smaller fraction of costs outside of manufacturing. Equation (A-5) then implies  $s_E = 0.02$ , which leaves 0.48 of total costs for labor and capital costs. Insofar as wages account for about 75 percent of value added in the national income accounts, we set  $s_H = 0.36$ ,  $s_K = 0.12$ .

As is explained in the text, we assume that in the long run, the number of firms is such that equation (A-1) is satisfied, implying that in the steady state  $s_\phi$ , the share of fixed costs in total costs, must equal

$$(1 - s_E - s_M) \frac{N\Phi}{F(K, zH)} = \frac{\mu - 1}{\mu}. \tag{A-6}$$

Hence, our calibration of this parameter follows from our choice of  $\mu$ , discussed ahead. (Note that  $s_\phi$  does not refer to costs in addition to the four categories previously listed. The fixed costs are a subset of the costs already counted once as labor and capital costs.)

The calculations just explained imply that the share  $\theta^{dom}$  of total energy use that is domestically produced is 0.83. They also explain why we set  $\theta^h$ , the share of total energy use that is direct household use, equal to 0.4.

The parameter  $\eta^g$ , indicating the steady-state value of  $H^g/H^s$ , is set equal to 0.17, the average ratio of government employment (summing employment by federal, state, and local governments) to total employment over the postwar period.

This completes our specification of the parameters describing balanced growth. We turn next to the remaining parameters of the production technology of the private non-energy sector. As the functions  $Q$ ,  $F$ ,  $G$  are all assumed to be homogeneous of degree one, the only parameters that occur in the log-linear approximation to our equilibrium conditions are, in the case of each function, the elasticity of the function with respect to each factor (only one free parameter per function as they must sum to 1) and the elasticity of substitution between the two factors. The elasticities of substitution enter the log-linear approximations to those equilibrium conditions involving marginal products. All of these elasticities are evaluated at the factor mix that occurs in the steady-state equilibrium. The elasticities with respect to the individual factors are implied by the steady-state share parameters already discussed; for example, the elasticity of  $G$  with respect to  $E$  must equal  $s_E/(s_E + s_M)$ , and the elasticity of  $Q$  with respect to  $V$  must equal  $1 - \mu(s_E + s_M)$ . (It will be observed that for both our values of  $\mu$ , each of these elasticities is positive.) It thus remains only to specify the elasticities of substitution. The values given in Table 1 for  $\epsilon_{GV}$  and  $\epsilon_{EM}$  are based on the econometric estimates reported in the Appendix of Rotemberg and Woodford (1993). The value of 1 for  $\epsilon_{KH}$  (which would follow from a Cobb-Douglas production function for value added) is standard in the real business-cycle literature and in a great many other computational, general equilibrium studies.

We next consider the parameters of household preferences. As noted above, the rate of time preference is implicitly determined by our specification of  $r$ . It is useful to discuss the utility function  $U(A, H)$  in terms of Frisch demand functions  $A^d(w^A, \lambda)$ ,  $H^s(w^A, \lambda)$  that it implies, where  $w^A$  denotes the "consumption wage" defined in Section 3, and  $\lambda$  denotes the representative household's marginal utility of wealth (with wealth in units of the composite good  $A$ ).<sup>22</sup> In order for a steady-state balanced-growth path to be possible, it is necessary to make a homogeneity assumption on the Frisch demands.<sup>23</sup> Specifically, we assume that there

<sup>22</sup> For demonstration of how the equilibrium conditions can be written conveniently in terms of the Frisch demand functions, see Rotemberg and Woodford (1993). The discussion of the parameterization of the Frisch demand functions follows Rotemberg and Woodford (1992).

<sup>23</sup> This is equivalent to a homogeneity assumption on the function  $U$ . For further discussion of the class of functions  $U$  satisfying this condition, see King, Plosser, and Rebelo (1988) or Rotemberg and Woodford (1992).

exists a  $\sigma > 0$  such that  $H^s(w^A, \lambda)$  is homogeneous of degree zero in  $(w^A, \lambda^{-1/\sigma})$ , and  $A^d(w^A, \lambda)$  is homogeneous of degree one in  $(w^A, \lambda^{-1/\sigma})$  (the homogeneity assumption referred to in Sections 2 and 3 that is important for the result that a tax on direct household use of energy has no effect on non-energy output). In our numerical work we furthermore specify the value of 2 for  $\sigma$ . As noted in Table 1, this value implies that the elasticity of consumption growth (specifically, growth in consumption of the aggregate  $A$ ) between two periods, with respect to the real rate of return between those periods (also measured in terms of the composite good  $A$ ), with hours worked holding constant, is equal to 0.5. This value (which follows Rotemberg and Woodford, 1993) is within the range of values consistent with a variety of studies of the relation between intertemporal substitution in consumption and asset prices. (A value of 1 is common in the real business-cycle literature.)

The only features of the Frisch demands that matter for the log-linear approximation to the equilibrium conditions are the elasticities of the functions with respect to their two arguments, again evaluated at the steady-state equilibrium. However, the homogeneity assumption just stated implies that all four elasticities are uniquely determined once we specify values for  $\sigma$  and any one of the elasticities. We choose to calibrate the model in terms of a specified value for  $\epsilon_H w$ , the elasticity of the Frisch labor-supply function with respect to the consumption wage, because this particular elasticity (sometimes called the "intertemporal elasticity of labor supply") is both familiar and the subject of a large number of econometric studies. The value that we assume (again following Rotemberg and Woodford, 1993) is at the high end of the range of values obtained from panel-data studies, though it is considerably smaller than the values most often assumed in the real business-cycle literature (often 4 or more).

The remaining feature of household preferences to specify is the aggregator function  $A(C, E^h)$ . Again, because we assume that the function is homogeneous degree one, the only parameters for which numerical values are needed are the elasticities of  $A$  with respect to its two arguments and the elasticity of substitution between the two arguments, again evaluated at the steady-state equilibrium consumption bundle. The elasticities with respect to the arguments are implied again by the share parameters specified in the foregoing. For example, the elasticity of  $A$  with respect to  $C$  is given by

$$\frac{C}{C + p_E E^h} = \frac{s_C(1 - s_M)}{s_C(1 - s_M) + \frac{d^h}{1 - \theta^h} s_E} \quad (\text{A-7})$$

Thus, it remains only to specify  $\epsilon_{CE}$ . Our value is taken from the econometric study by Houthakker, Verleger, and Sheehan (1974).

We finally describe the parameters that specify the product market structure. As noted in the text, all of the models that we consider amount to different specifications of the mark-up function  $\mu(X/Y)$  in equation (6). The features of this function that matter for the log-linear approximation to the equilibrium conditions are its value  $\mu$  in the steady-state equilibrium and the elasticity of the function with respect to its argument  $X/Y$ , also evaluated at the steady-state value of that argument. In the case of the competitive model, we specify  $\mu = 1$  and  $\epsilon_{\mu} = 0$ . In the case of the monopolistically competitive (or "constant mark-up") model, we specify  $\mu = 1.2$  and  $\epsilon_{\mu} = 0$ . In the case of the oligopolistic (or "variable mark-up") model, we specify  $\mu = 1.2$  and  $\epsilon_{\mu} = 0.15$ . As we discuss further in Rotemberg and Woodford (1992), the amount of market power assumed in the steady state in the case of the imperfectly competitive specifications (prices 20 percent in excess of marginal cost) is within the range of estimates obtained by a number of studies of U.S. industries. In that same paper we show that the implicit collusion model implies theoretical bounds on the value of  $\epsilon_{\mu}$ , namely, that  $0 < \epsilon_{\mu} < \mu - 1$ . The value that we assume here satisfies the theoretical bound. These parameter values for the implicit collusion model also coincide with those that are shown in Rotemberg and Woodford (1993) to predict effects of oil-price shocks that are similar to those observed during the period 1947–1980.

In the case of the oligopolistic model, it is also necessary to specify a value for the parameter  $\alpha$  which appears in the definition of  $X$  provided in Rotemberg and Woodford (1992). This parameter indicates the expected rate of growth of a given oligopoly's share in total expenditure. We assume  $\alpha = 0.9$ , because, as is discussed in the Appendix of Rotemberg and Woodford (1992), this value is consistent with the existence of an equilibrium with imperfect collusion (a binding incentive-compatibility constraint) in the case of oligopolies with no more than ten firms.

Finally, in the case of either of the imperfectly competitive models, we must specify the parameter of  $\rho$  in equation (A-3). We set this arbitrarily at 0.2. This parameter does not seem to have an important qualitative effect on our results as long as it is relatively small (adjustment of number of firms is not too fast).

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