Chapter 6. The role of induced technical change in simulation outcomes

6.1 Introduction

Among the more widely discussed aspects of environmental policy is the role of endogenous or induced technical change (ITC). It is likely that firms would react to changes in environmental policy by investing in R&D projects and restructuring production. These investments could lead to lower emissions and emissions growth but also to reductions in the associated economic costs. The presence of ITC lowers the economic costs of achieving a given environmental target or, equivalently, allows more aggressive reductions for a given willingness-to-pay (Goulder, 2004).

It is important to note what IGEM contributes to an analysis of ITC. IGEM is specified and estimated in a manner that isolates the portion of observed technical change that is the outcome of price-induced innovation within each industry. IGEM combines the estimated patterns of induced innovation with substitution among inputs in response to evolving trends in relative prices. The end result is an estimate, unique to each scenario, of the rate, direction and magnitude of price-induced technical change. This estimate is based on historical patterns of induced innovation which are invariant across scenarios.

IGEM's representation of price-induced technical change provides an economical characterization of this phenomenon. There is a growing theoretical literature on the impacts of firm, industry and economy-wide ITC, but there is relatively little empirical research to inform it. To remedy this IGEM posits a theoretical model of production and an associated estimation strategy. IGEM captures the historical pattern of industry innovation without modeling an explicit process that underlies it. In short, IGEM portrays the time patterns of innovation outcomes. A policy change introduced into IGEM alters the patterns of relative prices and so "induces" changes in productivity through policy-invariant patterns of innovation. The full measure of the effects of ITC depends on the continuing trends in innovation.

In considering the quantitative importance of ITC in policy simulations, we discuss two IGEM experiments involving differing policies, model vintages and methodological approaches. At the request of the Science Advisory Board (SAB) of the U.S. Environmental Protection Agency (EPA), the first involves isolating the role of ITC in measuring the economic costs of compliance with the Clean Air Act of 1970. The results here arise from a forerunner to the analysis presented in Chapter 3, Section 3.3. The second is part of our comprehensive analysis of climate change policy presented in Chapter 5. Of particular interest in these two assessments is the robustness of our findings at the macroeconomic level. The relative importance of ITC in explaining the changes in consumption, investment, the capital stock and labor demand and supply is broadly similar across the two very different experiments.

6.2 The role of induced technical change in complying with the Clean Air Act

A feature of each of the production models in IGEM is that an industry's productivity growth can be biased toward some inputs and away from others. By allowing biased productivity growth, the production models separate price-induced changes in factor use from those resulting from technical change. The rate of productivity growth in each industry consists of a temporal component that varies with time but not with policy conditions and an endogenous component that varies with policy-induced changes in relative input prices. In the version of IGEM used here, the endogenous components of technical change are represented by functions of time, estimated from historical data. For the economy as a whole, productivity growth then depends on the combination of forces operating within each producing sector and the mix of industries underlying the economy's expansion path.

We next examine the importance of endogenous productivity growth in simulating the counterfactual removal of the CAA compliance costs. This is accomplished by creating a new base case with the econometrically estimated factor biases in each industry set to zero. With no biases, productivity growth within each sector is limited to the exogenous component, which is invariant across policy alternatives. Comparing policy simulations with and without biases of technical change, we are able to isolate the impact of induced technical change. Productivity differences between the base and counterfactual simulations depends entirely on changes in the composition of economic activity, since there is no price-induced productivity change.

Table 6.1 and Figures 6.1 through 6.4 show the macroeconomic consequences of eliminating CAA compliance costs with and without ITC. With endogenous productivity growth, the cost reductions have a favorable and balanced impact on real GDP (Figure 6.1), consumption (Figure 6.2), and the expansion of capital (Figure 6.3); all increase by generally similar proportional amounts. There appears an economy-wide substitution toward capital and away from labor with larger adjustments for the former and much smaller ones for the latter.

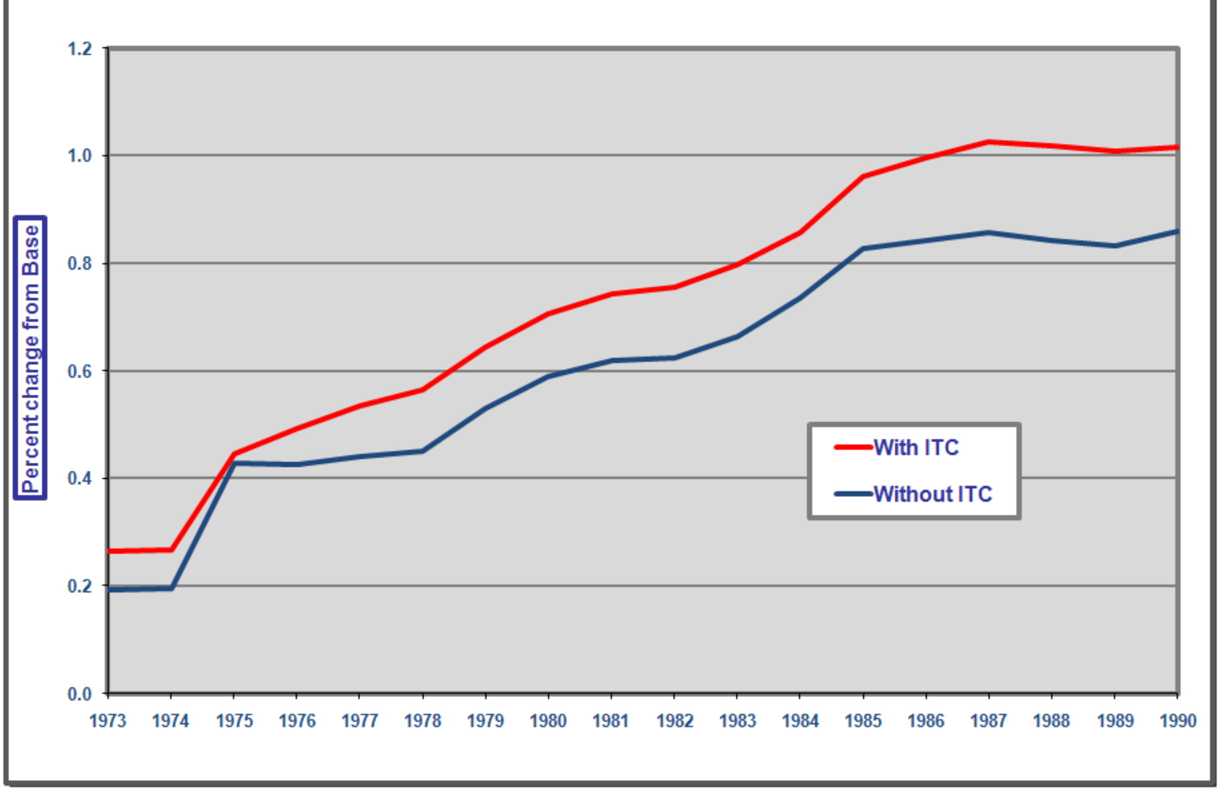
Indeed, with the exception of the somewhat larger impacts occurring immediately, the labor market is on average relatively unaffected by the removal of these costs (Figure 6.4).

Table 6.1: The Role Of Induced Technical Change

The average percentage change from Base, 1973-1990

	Counterfactual Elimination of the Clean Air Act Compliance Costs		
	With ITC	Without ITC	Difference
Real GDP	0.73	0.61	0.12
Consumption	0.73	0.58	0.15
Capital Stock	0.88	0.80	0.08
Labor Demand (Supply)	-0.05	-0.02	-0.03

Figure 6.1: Impacts on Real GDP
Elimination of Clean Air Act Compliance Costs



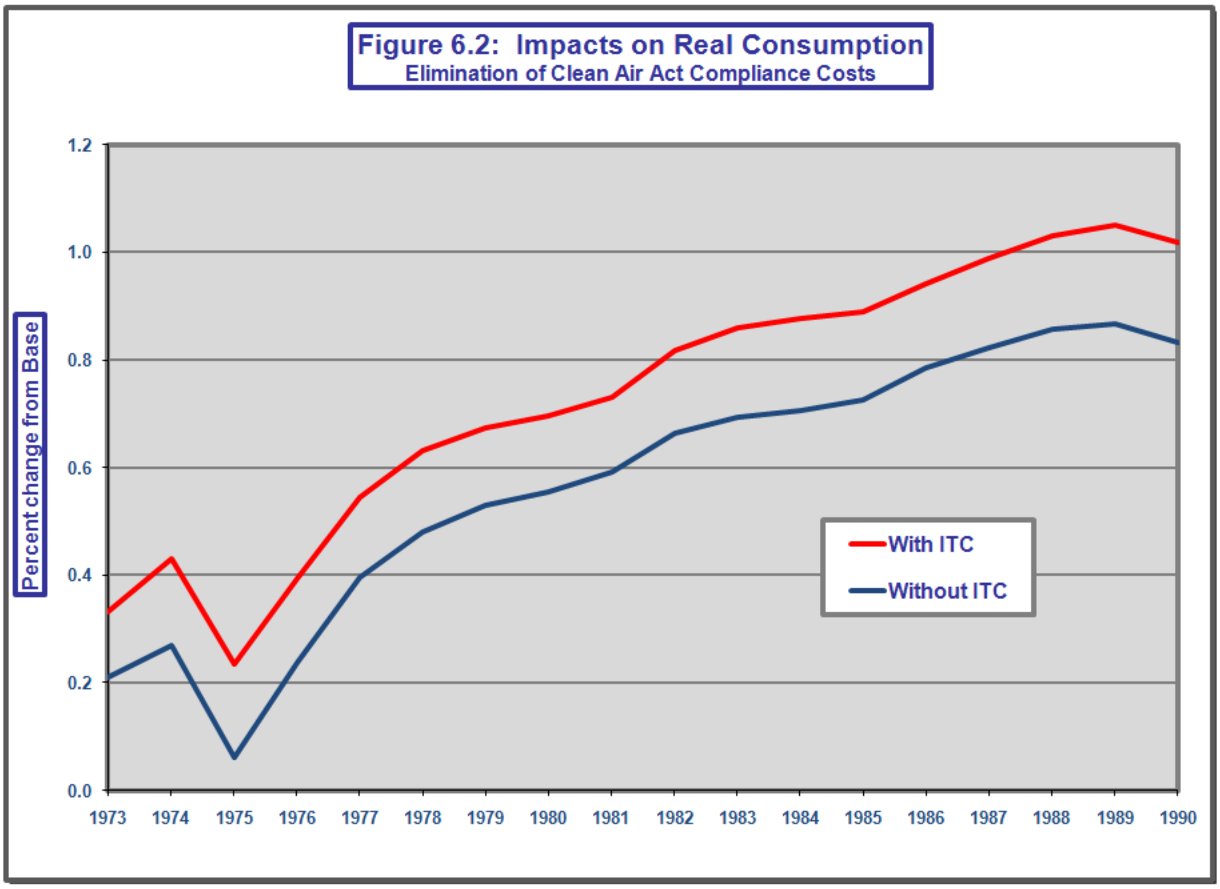


Figure 6.2: Impacts on Real Consumption
Elimination of Clean Air Act Compliance Costs
Percent change from Base
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1973
1974
1975
1976
1977
1978
1979
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1982
1983
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1988
1989
1990
With ITC
Without ITC

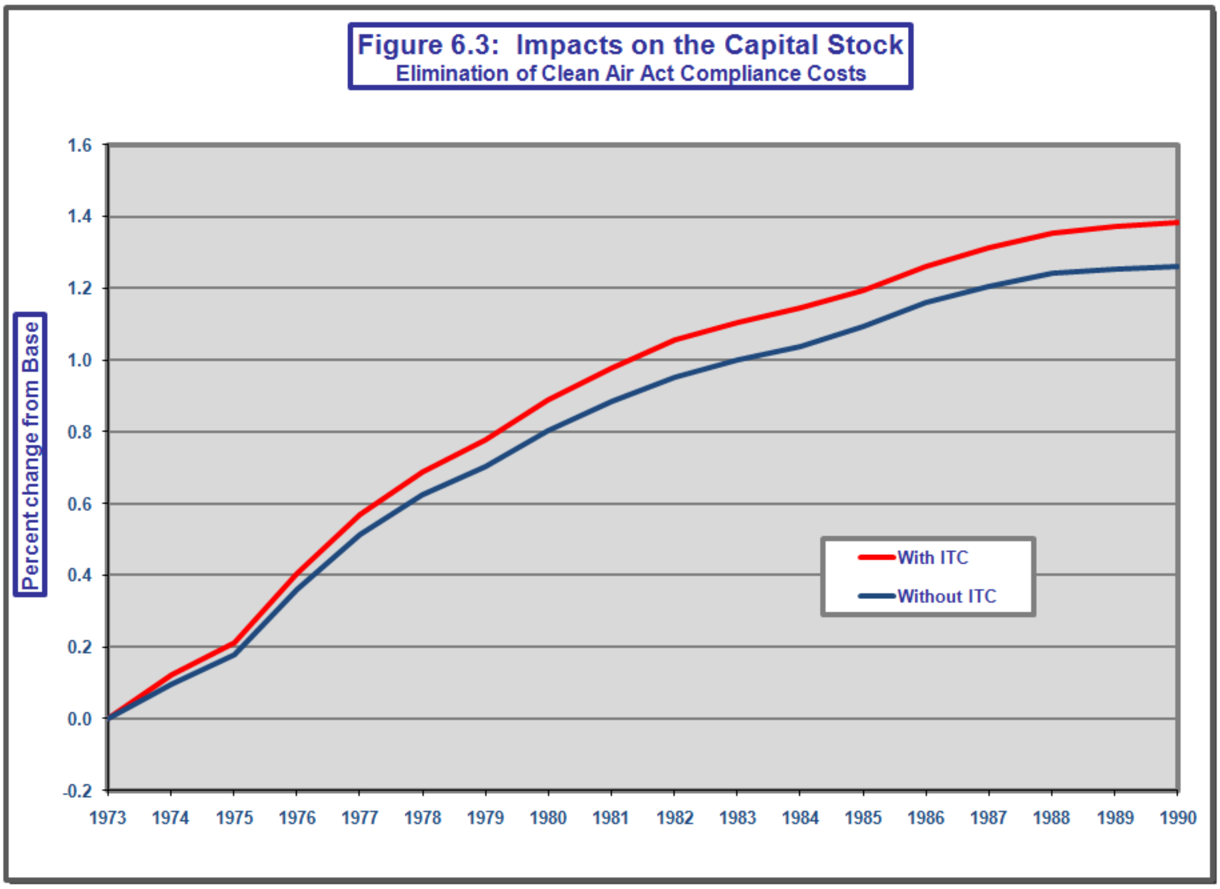
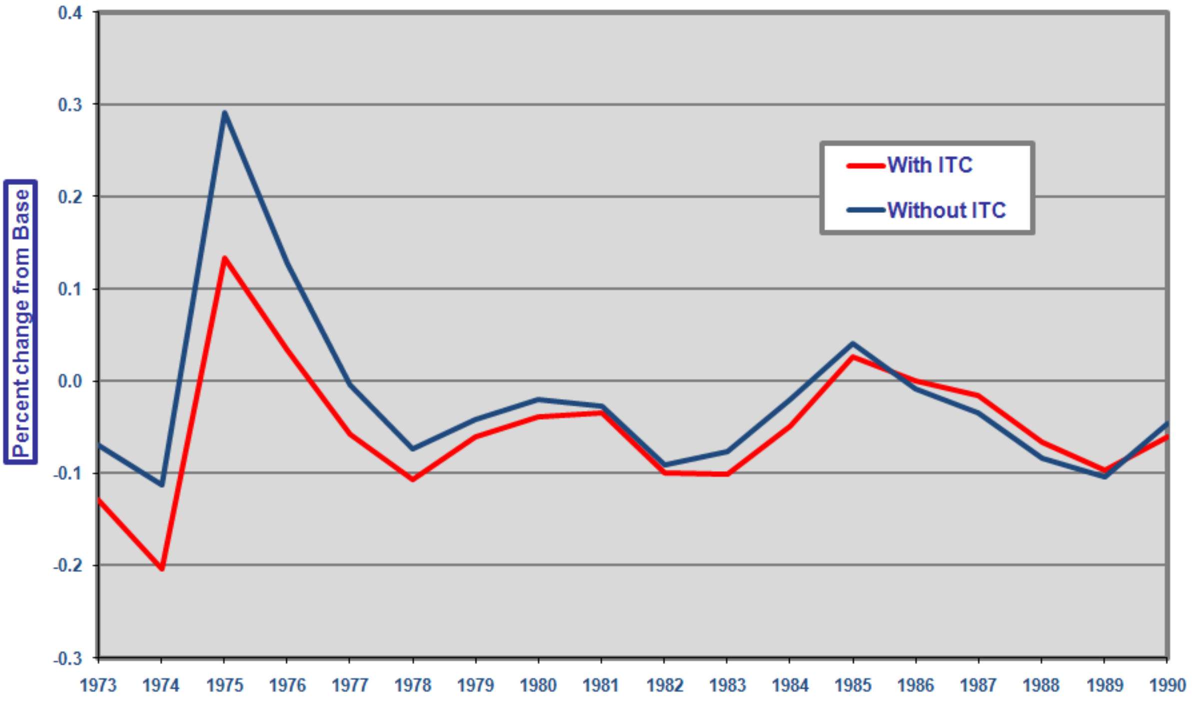


Figure 6.3: Impacts on the Capital Stock
Elimination of Clean Air Act Compliance Costs

Figure 6.4: Impacts on Labor Demand and Supply

Elimination of Clean Air Act Compliance Costs



The observed differences from eliminating the CAA costs with and without the technical biases depend on differences in the rates of capital accumulation, 1973-1990, and the synergy between capital accumulation and the compounding influences of endogenous productivity growth. With the technical biases, elimination of the CAA costs increases the capital stock by an average of 0.9 percent and real GDP and consumption each by an average of 0.7 percent. Without the technical biases, these average increases are reduced to 0.8 and 0.6 percent, respectively. More precisely, when the technical biases are removed, the gains from removing the CAA costs average 9 percent less for the capital stock, 16 percent less for real GDP, and 21 percent less for real consumption. In round figures then, endogenous productivity growth contributes from ten to twenty percent to the overall benefit of eliminating the CAA compliance costs.

It is interesting to note changes in the composition of industrial output with and without ITC. Figure 6.5 shows these effects. As the expansionary effects of CAA cost removal are smaller without ITC, there is the expectation of smaller gains for industrial “winners” and larger losses for industrial “losers.” While generally this is the case, there are exceptions. The increases in metal mining, construction, lumber and wood, stone, clay and glass, primary and fabricated metals, and motor vehicles and other transportation equipment are relatively unaffected by the absence of ITC. This is particularly relevant as motor vehicles is among the largest beneficiaries of CAA cost removal, petroleum refining and electric utilities being the other two, and as metal mining and primary metals are among the sectors next most benefitting. Finally, although extremely small in magnitude, the finance, insurance and real estate industry is the lone case in which the absence of ITC improves the gains from CAA cost removal, illustrating that relative price changes need not inevitably secure a beneficial productivity effect.

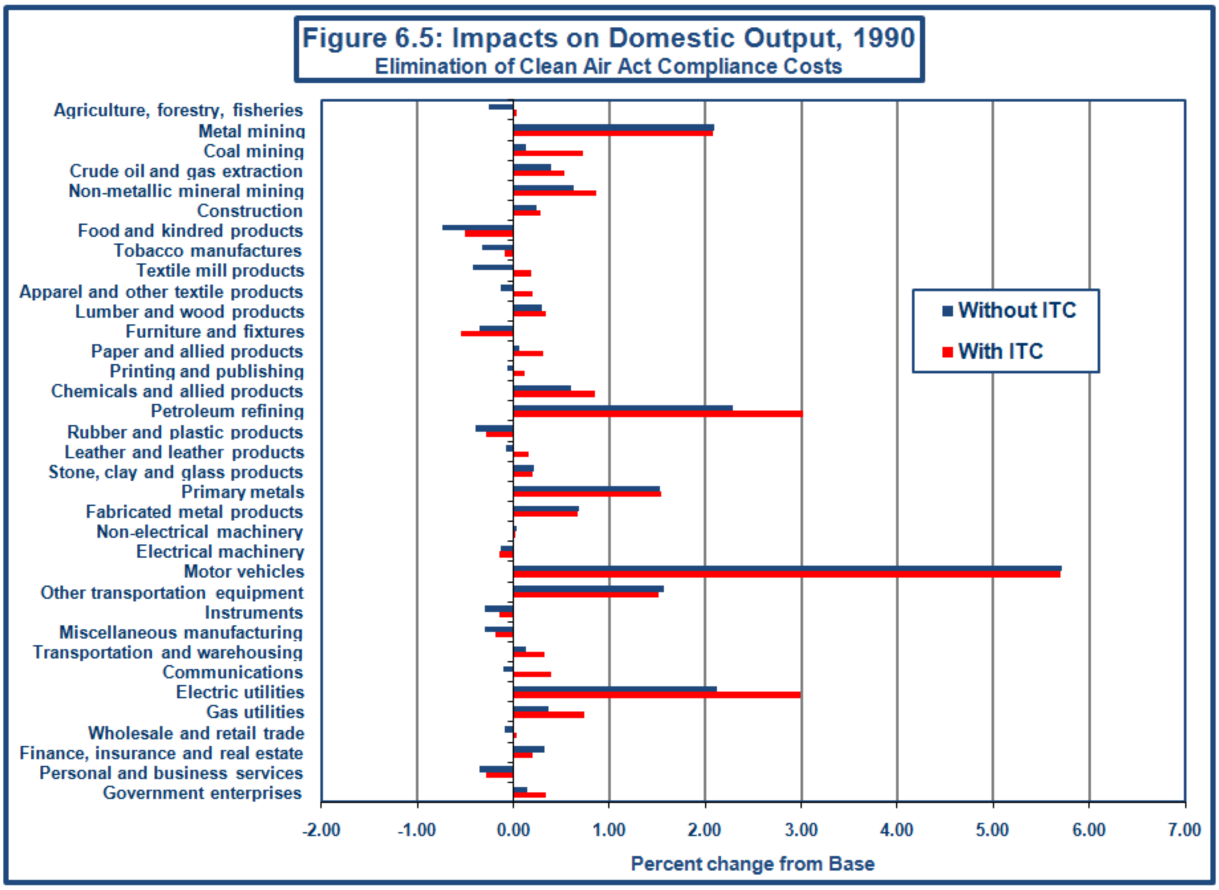


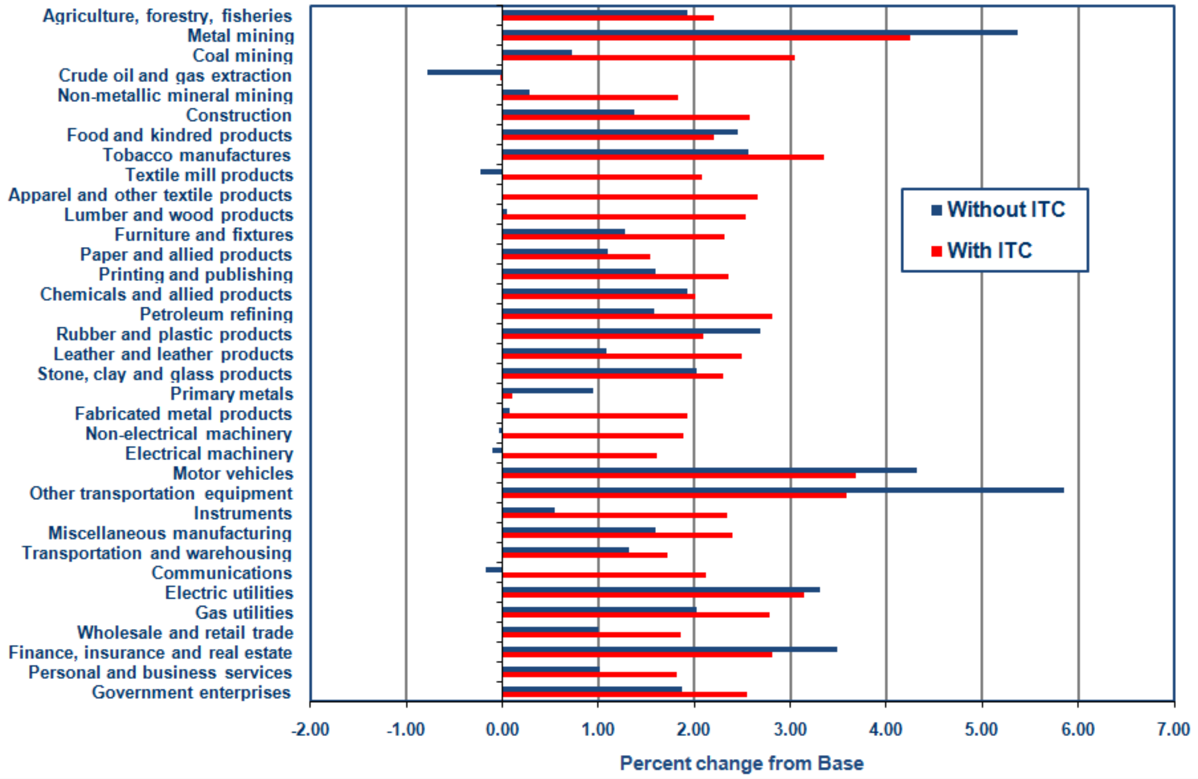
Figure 6.5: Impacts on Domestic Output, 1990

Elimination of Clean Air Act Compliance Costs

Since capital accumulation is central to the results, the allocation of capital without ITC is also of interest. With less capital and a smaller economy, there is a presumption of smaller capital-labor ratios without endogenous productivity growth. As shown in Figure 6.6, this is generally the case but there are exceptions. Metal mining, food and kindred products, rubber and plastics, primary metals, motor vehicles and other transportation equipment, electric utilities and finance, insurance and real estate all experience increases in their capital-labor ratios in the absence of ITC. Part of this obviously is driven by the output effects described above. Equally important, however, is the phenomenon that the elimination of ITC turns relatively capital-saving sectors into relatively capital-using sectors.

Figure 6.6: Impacts on Capital-Labor Ratio, 1990

Elimination of Clean Air Act Compliance Costs



Eliminating the CAA compliance costs after removing endogenous technical change is analogous to restoring lost productivity growth. Since the CAA costs rise over time, yielding their full proportional impact by 1990, the temporal pattern of unit cost reductions is not unlike what occurs with endogenous productivity growth. The elimination of the CAA compliance costs boosts real GDP and consumption (Figures 6.1 and 6.2) by lowering prices in all periods.

By raising real rates of return and lowering the rental price of capital services, there also are increases in current real savings and investment which increases the availability of capital, 1973-1990 (Figure 6.3). Thus, the observed differences from eliminating the CAA costs with and without endogenous technical change depend on differences in the rates of capital accumulation over the period of analysis and the dynamic interactions that follow from endogeniety.

ITC's contribution of ten to twenty percent to the overall benefit means that eighty to ninety percent of the benefit arises solely from the consequences of substitution and economic restructuring. The contribution of endogenous productivity growth is small in comparison to the overall gains from CAA cost removal, but serves to quantify the dynamic impact of induced changes in technology. However, the absence of endogenous technical change does not alter the conclusion that the costs associated with CAA compliance are harmful to economic performance nor does it alter the causal chain of adjustments that lead to this conclusion.

6.3 The role of induced technical change in climate change policy

In the version of IGEM supporting this analysis, there is an autonomous component of technical change that varies with time but not with environmental policy and an endogenous component that varies as a result of policy-induced price changes. The endogenous components are part of a state-space model of producer behavior in which technological trends and factor biases follow a mean-reverting, stationary, first-order autoregressive process. The producer models are estimated from historical data, using a two-step Kalman filter. This specification allows for a full characterization of the non-price time patterns in innovation but is more flexible in representing the patterns of technical change in the historical data.

To ascertain the importance of ITC in the results of Chapter 5, two additional simulations are performed. These draw information from the base case and from the two policy cases with 15% limits on the use of international offsets. In each case, model results are used to calculate the magnitude of ITC. Next, the differences between the policy cases and the base case are determined. These differences measure the changes in ITC that are induced by the relative price changes in IGEM from the policy variations. The two policy cases then are re-run, netting out or negating these differences. This is equivalent to eliminating the impacts of policy-induced technical change from each of the model runs.

The experiment yields the following findings. First, the economic costs of mitigation policy are lower with ITC than they are in its absence (see Table 6.2). The benefits of ITC are proportionally greater for consumption and the process of capital formation than they are for overall spending and income but, nevertheless, there are measurable benefits economy-wide.

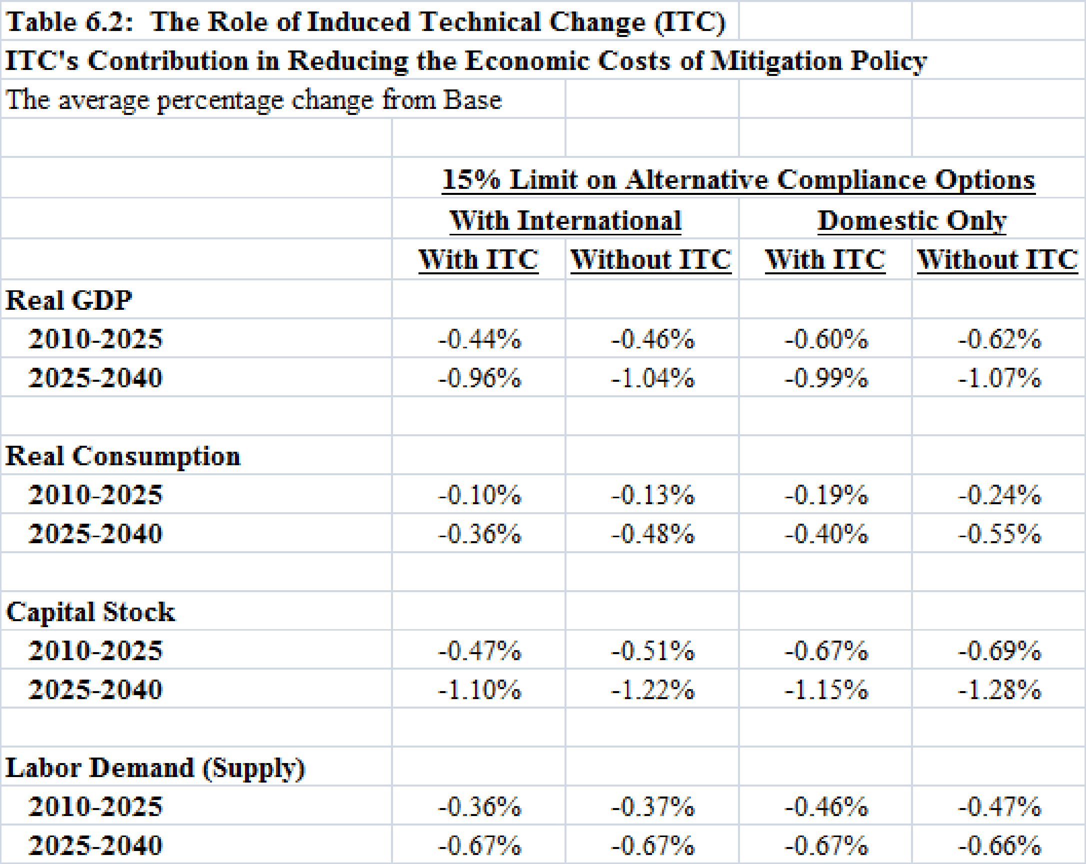


Table 6.2: The Role of Induced Technical Change (ITC)

ITC's Contribution in Reducing the Economic Costs of Mitigation Policy

The average percentage change from Base

	15% Limit on Alternative Compliance Options			
	With International		Domestic Only	
	With ITC	Without ITC	With ITC	Without ITC
Real GDP				
2010-2025	-0.44%	-0.46%	-0.60%	-0.62%
2025-2040	-0.96%	-1.04%	-0.99%	-1.07%
Real Consumption				
2010-2025	-0.10%	-0.13%	-0.19%	-0.24%
2025-2040	-0.36%	-0.48%	-0.40%	-0.55%
Capital Stock				
2010-2025	-0.47%	-0.51%	-0.67%	-0.69%
2025-2040	-1.10%	-1.22%	-1.15%	-1.28%
Labor Demand (Supply)				
2010-2025	-0.36%	-0.37%	-0.46%	-0.47%
2025-2040	-0.67%	-0.67%	-0.67%	-0.66%

Second, the role of ITC is small in comparison to the much larger effects of substitution and economic restructuring (Jorgenson et al., 2000). Over the period 2025-2040, ITC reduces the cost of economic adjustment by 7 to 8% for GDP, by 9 to 10% for the capital stock and by 25 to 26% for household consumption. These relative magnitudes are consistent with findings summarized in the Pew Center report (Goulder, 2004) and with other contributions to the recent literature (Nordhaus, 2002 and Wing, 2003). Moreover, indicative of robustness, the longer-run proportional effects on consumption and the capital stock are nearly identical to the results from the Clean Air Act analysis described in Section 6.2.

Finally, the favorable impacts of ITC are cumulative. There are measurable and positive benefits and these increase with the passage of time. These ITC effects arise solely from the interactions of the estimated factor biases and the policy-induced changes in relative prices. There is no empirical basis for adjustments in the biases themselves, although Popp (2001 and 2002) and Wing and Eckaus (2004) have taken important steps in this direction. If policy were to provide incentives designed to alter the biases, such as targeted R&D and investment tax credits, these results could be magnified. The role of ITC would become more significant, reflecting not only relative price changes but also policy-induced innovation, reflected in non-price changes in factor intensities.

A secondary feature of these simulations, shown in Table 6.3, is that permit prices are marginally lower in the absence of ITC. The reasons for this are twofold and depend on the consequences of ITC at the sector level, as shown in Figure 6.7. In Figure 6.7, negative numbers indicate that ITC is working to lower prices. Therefore, eliminating this impact harms this industry and the overall economy. Positive numbers indicate that ITC is working to raise prices. Eliminating this impact helps this industry and the overall economy.

Eliminating the ITC effects that arise from a given policy has an overall negative effect on economic performance (Table 6.2). As evidenced in Figure 6.7 by the economy-wide, value-share weighted average of the ITC effects in each industry, the economy is smaller when these ITC effects are netted out of the simulation. As the economy is smaller, GHG emissions are lower and permit prices do not need to be as high to achieve the required abatement.

Table 6.3: GHG Permit Prices

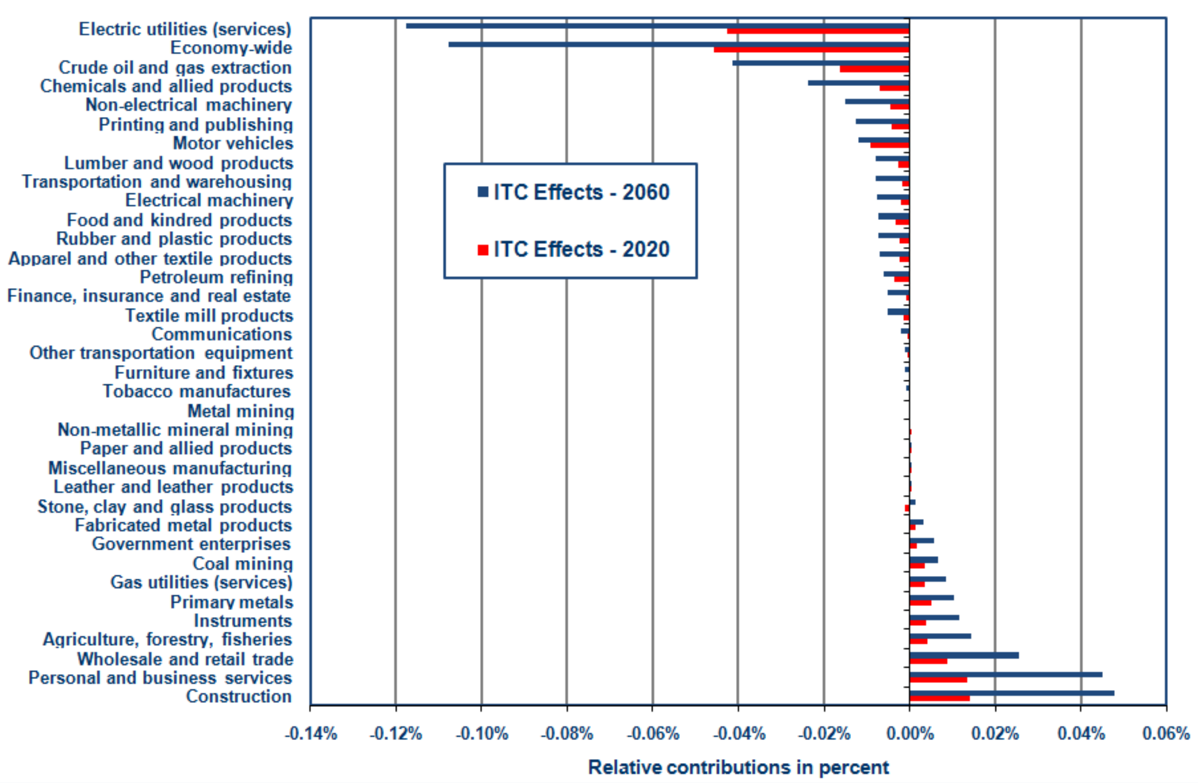
15% Limit on Alternative Compliance Options

	With Induced Technical Change		Without Induced Technical Change	
	With International	Domestic Only	With International	Domestic Only
2010	$2.1	$5.8	$2.1	$5.8
2015	$3.6	$8.0	$3.6	$7.9
2020	$5.8	$9.9	$5.8	$9.8
2025	$9.8	$11.8	$9.6	$11.6
2040	$22.2	$22.3	$21.6	$21.6

Dollars per metric ton of carbon dioxide equivalent.

Dollars in terms of GDP's purchasing power in the year 2000.

Figure 6.7: Induced Technical Change at the Interindustry Level



Eliminating ITC effects also has implications for energy use and GHG emissions. This is illustrated by focusing on three sectors in Figure 6.7 – electric utilities, trade, and services. ITC in the electric utilities sector plays the dominant role in the overall ITC effect. In the presence of ITC electricity prices are lower and demand is higher than without ITC. In short, the empirically observed ITC in this sector works somewhat against the goals of climate change policy. Since ITC helps to lower electricity prices, unconstrained energy use and emissions are higher which means that permit prices also have to be higher to achieve a given emissions reduction. However, in the absence of ITC, electricity prices are higher and demand is lower. These imply a corresponding reduction in energy inputs to this sector and, hence, lower emissions. The absence of ITC in the electricity sector reduces the electricity intensity of the economy which means that permit prices do not have to rise as high to satisfy the emissions constraint.

ITC in trade and services has different implications but contributes similarly to this outcome. The ITC effects calculated for these sectors work to raise their prices. This is harmful to their growth and to the overall economy. Eliminating these ITC effects lowers the relative prices of trade and services, improves their relative performance and helps the economy. But these sectors are not energy or emissions-intensive. The restructuring that occurs in the absence of these calculated ITC effects yields an economy that is less energy and emissions intensive and, again, the permit prices that are necessary to achieve the targeted reduction are marginally lower.