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Abstract. Anticipation of an International Environmental Agreement provides an incentive for countries to change their production behavior prior to negotiations in order to gain a favorable bargaining position. Increased historical production figures at the time of negotiations may influence the magnitude of the baseline from which cutbacks will be specified. In this paper we empirically measure the magnitude of such strategic production behavior in the case of the Montreal Protocol on Substances that Deplete the Ozone Layer of 1987. Due to data limitations we specify a two player Nash–Cournot game between the United States and the rest of the world. We find evidence of asymmetric strategic behavior, which resulted in a net increase of aggregate world chlorofluorocarbon (CFC) production.

Key words: chlorofluorocarbons, international environmental agreements, Montreal Protocol, strategic production behavior

JEL classification: Q20, O57, C30

1. Introduction

The Montreal Protocol on Substances that Deplete the Ozone Layer (1987) is considered to be one of the most successful and important pieces of international environmental legislation in history. This treaty and successive agreements place binding limits on the production and consumption of the main ozone depleting chemicals, chlorofluorocarbons (CFCs), halons, carbon tetrachloride, methyl chloroform, hydrofluorocarbons and methyl bromide.[1] These chemicals have been widely used as refrigerants, coolants, aerosol propellants and industrial solvents. All of these compounds are extremely stable, nonflammable, non-toxic, non-corrosive and cheap to produce (Benedick 1991). However, their use has resulted in a thinning of stratospheric ozone around the globe. The resulting increase in the intensity of UV-rays reaching the surface of the earth may augment skin cancer rates among humans, decrease plankton production in the oceans, and negatively affect agricultural production.

The Montreal Protocol and the pursuit of other international environmental agreements affecting the environment has generated an extensive theoretical literature that examines strategic behavior in the formation of an international environmental agreement (e.g. Barrett 1990; Carraro and Siniscalco 1993; Hoel and Schneider 1997).[2] Fewer papers have suggested that the expectation of a forthcoming agreement may lead actors (governments or sources of pollution) to alter their behavior.[3] One reason this may occur is that environmental agreements often specify cutbacks in the production of harmful substances relative to a negotiated baseline level of production.[4] If producers anticipate the future adoption of an agreement, forcing them to reduce their production by a certain amount below some baseline, they may have an incentive to increase production before the agreement is struck to influence the choice of baseline adopted in the agreement.

In this paper we examine changes in the strategic behavior of CFC producers prior to the adoption of the Montreal Protocol in 1987. Because of severe limitations on the availability of CFC production data, we are forced to conduct a highly aggregative empirical analysis of the strategic behavior of United States producers of CFCs and the behavior of producers in the rest of world for which data are available.

This paper does not attempt to provide formal tests of the specific hypotheses about anticipatory strategic behavior offered in the theoretical literature. Rather, the purpose is to examine the implications for such an agreement and consider methods for empirical measurement of these effects in the years immediately preceding the Montreal Protocol.

The next section briefly discusses the history of CFCs and provides an account of the negotiations leading up to the Montreal Protocol. This section serves as the motivation for the model specification given in Section 3. Section 4 provides estimation results and a discussion as to their implications. Section 5 contains some concluding remarks and suggestions for future research.

2. Background

Chlorofluorocarbons were invented in 1928. They made possible the mass proliferation of air conditioning and refrigeration (Cagin and Dray 1993). The pattern of global and United States production of CFCs is shown in Figure 1.[5] Production of the rest of the world is obtained by subtracting US production from global production figures. World production of CFCs rose from 544 metric tons in 1934 to 812,522 metric tons in 1974 (Alternative Fluorocarbons Environmental Acceptability Study, 1997). This is equivalent to an average annual growth rate of 23.51% between 1934 and 1974.

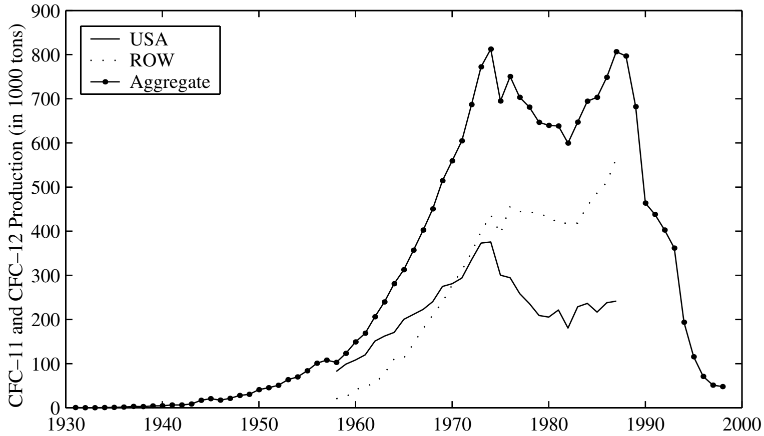

Figure 1. Production of CFC-11 and CFC-12 in the USA and the rest of the world.

In 1974 Molina and Rowland published their research on the breakdown of CFCs in the earth's stratosphere and the resulting destruction of ozone molecules. The USA, followed by Canada, Norway and Sweden, banned the use of nonessential aerosols in March of 1978. A number of international scientific conferences that addressed the possible consequences of ozone depletion were held in years following. In addition the United Nations Environment Programme (UNEP) pushed to have an international convention with the goal of negotiating a binding agreement. During these years, from 1974 until the end of 1982, there was a reversal in the global production trend. Global production of CFCs declined on average by 3.54% per year. During this time the ban of CFCs in nonessential uses by the USA, Canada, Sweden and Norway was followed by a commitment of the European Community in 1980 to implement a capacity cap and reduce aerosol use by thirty percent.

An *ad hoc* working group, convened by UNEP, began to negotiate a convention on research, monitoring, and data exchange in 1982, but failed to agree on a protocol for controlling CFCs by 1985. During this time, however, increased public and political pressure made it apparent that international diplomatic efforts to negotiate the regulation of CFC production was imminent. In March 1985, 43 nations convened in Vienna to complete work on the first international ozone convention, later titled the *Vienna Convention*. This non-binding agreement bound nations to "take appropriate measures" to protect the ozone layer. More importantly, all 43 signatory nations agreed to renegotiate for a binding agreement in 1987.

The negotiations leading up to the Montreal Protocol on Substances that Deplete the Ozone Layer were marked by the willingness of both the United

States' and some European governments to reach a binding agreement on the regulation of CFC production. There was, however, great resistance by industry groups on both sides of the Atlantic until late in 1986. The major producers did not "find enough scientific evidence" warranting restrictions on the production of ozone depleting substances. Richard Benedick, the chief negotiator for the United States notes that about 3 months prior to the scheduled start of negotiations a coalition of about 500 US producer and user companies changed their position and supported the international regulation of CFCs (Benedick 1991). Mostafa Tolba, the head of UNEP, notes that as a result of this, the US changed its position and supported a global freeze on CFC production followed by a series of reductions that would lead to a complete ban (Tolba 1998). He further argues that European chemical industries saw US industries as being a step ahead of them in developing substitutes for CFCs, which could endanger their markets (Tolba 1998). Overall, the United States and EC disagreed over almost every issue at every step along the route to Montreal (Benedick 1991). The 60 governments participating in the Montreal negotiations agreed to a binding protocol in 1987. Reductions in the production of CFCs were stated in terms of individual countries' 1986 levels of production (United Nations Environment Programme 2000). These reductions were revised and tightened in later amendments to the protocol.

Shortly after the adoption of the Montreal Protocol, empirical evidence linking CFCs to the destruction of ozone was found. The search for alternative compounds was successful and a trade fair on CFC substitutes was held in Washington, DC in January of 1988. Two months later Du Pont, one of the main producers of CFCs, announced the phase out of the production of CFCs.

Figure 1 shows a structural break in production during 1982. The previously stagnant or downward trend now reverted to an upward trend, resembling production patterns prior to the discovery of the harmful effects caused by CFCs. From 1983 to 1987, global production of CFCs grew by an annual average of 6.15%. This change in trend of production is curious, but alone it does not suggest anticipatory production behavior on the part of the United States and the rest of the world. However, the trend reversal does suggest that an empirical investigation into the possibility of anticipatory behavior is likely to yield interesting results.

3. Model Development

The theoretical model underlying the empirical analysis of this paper is assumed to be a Nash–Cournot model in which each nation/player chooses its production of CFCs in a particular time period based in part on what it believes will be aggregate production of CFCs in the rest of the world.[6] Each country's belief about CFC production in the rest of the world is confirmed in every time period so that the distribution of production levels across countries forms a Nash equilibrium in every time period.

Country-specific data on CFC production are not available. Aggregate global production figures from 1931 to 1995 were compiled via a confidential reporting mechanism by the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS). This dataset includes aggregate production figures for producers from the USA, Italy, France, Germany, United Kingdom, Greece, Belgium and Japan and their subsidiaries (AFEAS 1997).[7] The United States Tariff Commission reports production for the United States from 1958 until the present. Because country-specific production figures are not available for countries other than the United States,[8] we are led to consider a two-player Nash–Cournot game between the United States and the rest of the world.

Let U^{usa} be welfare for the United States and let U^{row} be welfare for the rest of the world in some time period. Similarly, let CFC^{usa} be total US production in a particular time period, and let CFC^{row} be the corresponding production for the rest of the world. Then, a pair $[CFC^{usa}, CFC^{row}]$ is a Nash equilibrium in a particular time period if the production levels solve (1) and (2) simultaneously:

$$\max_{CFC^{usa}} U^{usa} = U(CFC^{usa}, CFC^{row}, D^{usa}, P^{usa}, \text{Policy}) \tag{1}$$

$$\max_{CFC^{row}} U^{row} = U(CFC^{row}, CFC^{usa}, D^{row}, P^{row}, \text{Policy}) \tag{2}$$

Non-production exogenous variables that enter the welfare functions consist of demand, cost and policy variables for each player, as well as the opponent's production for the same time period. D^{usa} and D^{row} proxy for CFC demand side effects. P^{row} and P^{usa} indicate the cost of production for each player. *Policy* consists of slope dummies for time periods that could possibly affect pre-treaty behavior of each player.

Assuming for each $i \in$ (usa, row) U^i is strictly concave in CFC^i, the standard first-order conditions associated with the simultaneous maximization of (1) and (2) implicitly define the Nash best-response functions:

$$CFC^{usa} = f(CFC^{row}, D^{usa}, P^{usa}, \text{Policy}) \tag{3}$$

$$CFC^{row} = f(CFC^{usa}, D^{row}, P^{row}, \text{Policy}) \tag{4}$$

These Nash best response functions indicate how each player's optimal choice of production of CFCs changes due to a change in any of the exogenous variables on the right hand side. It is important to note that each player's optimal level of production depends on the opponent's choice of production for that same time period. *The nature of this dependence and how it changes over time is the primary focus of this paper.*

Of particular importance to this analysis is what Bulow et al. (1985) call "aggressiveness". To illustrate this concept, suppose the US producers of CFCs believe that producers in the rest of the world will increase their production of CFCs. Bulow et al. (1985) would call the behavior of US producers aggressive if they respond to this new belief with a significant increase in their own production; they would be called less aggressive if they respond with a smaller increase or decrease in production. Note the simple fact that the slope of their best response function captures the relative aggressiveness of US producers – a strong positive slope indicates relatively aggressive behavior, while a weaker, or negative, slope indicates less aggressive behavior. Of course, all this applies to producers in the rest of the world as well. An important focus of this paper is whether producers of CFCs became more or less aggressive in the years preceding the Montreal Protocol.

The high level of aggregation in this paper raises the question whether the second player (ROW) can act strategically, since it is a group of countries. Benedick's (1991) account suggests that the producers in the European Union, contained in the AFEAS (1997) dataset, had adopted a joint strategy in the negotiations. Japan which was responsible for roughly 10% of global production in 1986 adopted its own negotiating strategy, which followed the lead of the EU (Benedick 1991). We take this as evidence in support of the belief that the ROW player conducted coordinated behavior in the negotiations leading up to the Montreal Protocol. In all interpretations it should therefore be noted that the rest of the world here essentially contains producers from the European Union and Japan.

In accordance with the theoretical model, the matrix of explanatory variables should include exogenous variables that capture the cost and demand effects on the production of chlorofluorocarbons for each player, the opponent's production figures, as well as a vector of dummy variables capturing the changes in policy prior to the Montreal Protocol. The economic model used for later estimation is given in Equations (5) and (6):

$$CFC_t^{\text{usa}} = f(CFC^{\text{row}}, CFC^{\text{row2}}, CFC^{\text{row3}}, OIL_t, GDP_t^{\text{usa}}) \quad (5)$$

$$CFC_t^{\text{row}} = f(CFC^{\text{usa}}, CFC^{\text{usa2}}, CFC^{\text{usa3}}, OIL_t, GDP_t^{\text{row}}) \quad (6)$$

The left hand side variable for each model (CFC_t^{usa} and CFC_t^{row}) consists of the combined production of CFC-11 and CFC-12. As outlined in the theoretical specification of the model in Equations (3) and (4), the United States react to demand variables unique to the United States. The rest of the world reacts to a set of variables, which capture effects unique to the producers outside of the United States. A summary description of the variables and their meaning is given in Table I.

As a proxy for demand variables we used Gross Domestic Product for the United States and the aggregate purchasing power parity adjusted gross domestic product for countries contained in the AFEAS (1997) sample. This aggregate measure should be a reasonable proxy for the demand\market size for CFCs in the industrialized countries. We tested all of our series for non-stationarity using the test proposed by Kahn and Ogaki (1992). We fail to reject the null of stationarity, but acknowledge the fact that due to the limited length of the series, any test for stationarity has limited power. We used the price of oil in terms of 1995 US$ as a proxy for costs of production and capital. CFCs are a petroleum-based product; therefore, the world market price of oil should be a good proxy for the costs of inputs to production.

The history of production and consumption of CFCs, the discovery of their harmful effects on stratospheric ozone, and unilateral and international efforts leading to the adoption of the Montreal Protocol suggest three very distinct time periods before the Montreal Protocol was signed in 1987. Summarizing our discussion the three distinct time periods under study are therefore 1958–1974 (*Period I*), 1975–1982 (*Period II*) and 1983–1987 (*Period III*). During *Period I* the hazardous effects of chlorofluorocarbons on the environment were unknown. There were no policies limiting the production of these substances in any country. *Period II* captures the years after the publication of the paper by Molina and Rowland (1974), which were characterized by increased public attention, but no plans for an International Environmental Agreement. *Period III* starts with the year negotiations toward placing binding limits on CFC production and consumption began and ended with the adoption of the Montreal Protocol in 1987.[9]

In order to capture any changes in production behavior during these three time periods, the Policy variables included in the model consist of two slope dummy variables. To catch the possible changes in the opponent's production behavior during *Period II*, the slope shifter variable, CFC^{row2} takes on

Table I. Names and description of variables used in estimation

Variable name	Description
CFC^{usa}	US CFC production in metric tons
CFC^{row}	Rest of the world CFC production in metric tons
CFC^{usa2}	US Slope Dummy 1975–1982
CFC^{usa3}	US Slope Dummy 1983–1987
CFC^{row2}	ROW Slope Dummy 1975–1982
CFC^{row3}	ROW Slope Dummy 1983–1987
GDP^{usa}	United States GDP (1995 constant US$)
GDP^{row}	GDP of ROW countries (1995 constant US$)
OIL	Spot market price for barrel of crude oil (1995 constant US$)

the values of CFC^{row} during *Period II*. Similarly, the slope shifter variable for *Period III*, CFC^{row3}, takes on the values of CFC^{row} for the years in *Period III*. (CFC^{usa2} and CFC^{usa3} are obtained the same way). We assume the best response functions (5) and (6) and estimate:

$$\begin{aligned} CFC_t^{\text{usa}} = {} & \beta_0 + \beta_1 CFC_t^{\text{row}} + \beta_2 CFC_t^{\text{row2}} + \beta_3 CFC_t^{\text{row3}} + \beta_4 OIL_t \\ & + \beta_5 GDP_t^{\text{usa}} + \varepsilon_t \end{aligned} \tag{7}$$

$$\begin{aligned} CFC_t^{\text{row}} = {} & \gamma_0 + \gamma_1 CFC_t^{\text{usa}} + \gamma_2 CFC_t^{\text{usa2}} + \gamma_3 CFC_t^{\text{usa3}} + \gamma_4 OIL_t \\ & + \gamma_5 GDP_t^{\text{row}} + \eta_t \end{aligned} \tag{8}$$

We fail to reject the null hypothesis of linearity in the right hand side variables. In this two-player game, the USA and the rest of the world choose their production simultaneously and the opponent's choice of production enters the equation on the right hand side. The disturbance terms are not independent from all of the variables on the right-hand side in this model. We estimate Equations (7) and (8) via the three stage least squares (3SLS) estimator. Regressing the endogenous right hand side variables on US and rest of the world energy usage and intercept dummy variables for *Periods I* and *II* resulted in satisfactory instrumental variables for use in the 3SLS estimation.

4. Results

Table II provides the estimation results and summary statistics. These form the basis for interpreting how the production behavior of each player changed with respect to the opponent's behavior from *Period I* to *Period II* and to *Period III*. The obtained values indicate a good fit for the model. The Durbin—Watson statistics fall into the uncertainty region. This may hint at misspecification issues, which we cannot rule out due to the small sample size. The parameter estimates are, however, not very susceptible to alternate specifications.

The main question to be addressed by this paper is if nations did display anticipatory production behavior prior to the Montreal Protocol. In order to interpret the estimation results in a way that may answer this question one needs to look at each player's individual Nash best response function, and see if there are any statistically significant shifts from *Period I* to *Period II* and *Period III*.

The results presented in Table II show that the production behavior of both players changed with respect to their opponent's behavior from *Period I* (1958–1974) to *Period II* (1975–1982) and to *Period III* (1983–1987). The parameter estimates for CFC^{row}, CFC^{row2}, CFC^{row3}, CFC^{usa}, CFC^{usa2} and CFC^{usa3} are all significant at the 1% level. The parameter estimates for

Table II. 3SLS estimation results

Variable	Parameter estimate	t-Statistic
Reaction function USA		
Intercept	180356[b]	2.57
CFC^{row}	0.84[a]	6.50
CFC^{row2}	−0.23[a]	−5.34
CFC^{row3}	−0.26[a]	−4.38
GDP^{usa}	−31.58	−1.13
OIL	−2425.71[a]	−3.46
Durbin–Watson statistic	1.301	
df	24	
Reaction function ROW		
Intercept	−186547[a]	−7.09
CFC^{usa}	1.06[a]	4.15
CFC^{usa2}	0.63[a]	4.47
CFC^{usa3}	0.72[a]	2.90
GDP^{row}	30.04[c]	1.90
OIL	−750.18	−0.63
Durbin–Watson statistic	1.518	
df	24	
R^2 (System weighted)	0.9804	

[a] Significant at 1%.
[b] Significant at 5%.
[c] Significant at 10%.

CFC^{row}, CFC^{row3}, CFC^{usa2} and CFC^{usa3}, *which are all jointly significant* with CFC^{usa} and CFC^{row} respectively, indicate changes in slope of the players' best response functions from *Period I*. A positive parameter estimate for any of these variables indicates an increase in aggressiveness relative to *Period I*. An increase in aggressiveness in this context means that a player will respond to an increase in production by its opponent by producing relatively more output than it would have in the original period, assuming a positively sloped best response function. Should the best response function be negatively sloped, the player would react to such behavior by decreasing its production by a relatively smaller amount than it would have in the original time period.

During *Period I* the United States' Nash best response function is upward sloping in its opponent's production. A one ton increase in the production of chlorofluorocarbons by the rest of the world would cause the United States to produce an additional 0.84 tons during the years of 1958–1974. This behavior can be attributed to the mass proliferation of these cheap and incredibly useful chemicals during this time. Refrigerators as well as air conditioning units were being mass marketed during this time and there was a tremendous global demand for these substances.

The parameter estimate for CFC^{row2} indicates a decrease in slope of the United States' best response function for *Period II* (1975–1982). As shown in Table II, the slope decreases by 0.23. For these years after the discovery of the harmful effects of chlorofluorocarbons, the United States' producers would respond to a one ton increase in production by the rest of the world by increasing their own production by only 0.61 tons. Thus, they became less aggressive in *Period II*. This is probably due to the ban of CFCs in non-essential uses by the United States. It may also have been more costly to increase production of CFCs for United States producers during this period because of increased public pressure on the main producers.

Possible changes in slopes of the best response functions during *Period III* (1983–1987) will show if nations did in fact change their behavior in anticipation of the Montreal Protocol. The estimate for CFC^{row3} is −0.26, which means that each additional ton of CFCs produced by the rest of the world would result in a 0.58 ton increase in production by the United States. This result shows that the United States, during the years of 1983 until 1987, displayed slightly less aggressive production behavior in comparison to *Periods I* and *II*. This less aggressive production behavior could indicate some strategic behavior on the part of US producers. Even though Benedick (1991) argues that Du Pont had not yet developed substitutes for CFCs, they had previously invested significant resources into the development of substitutes. US producers may have therefore had an edge on rest of the world producers in the development of substitutes.

The rest of the world's production behavior can be interpreted in the same fashion. Table II reveals that during the years from 1958 until 1974, the rest of the world's reaction function was positively sloped. The estimate of CFC^{usa} indicates that for a one ton increase in US chlorofluorocarbon production, the rest of the world increased its production by 1.06 tons. Both players had an upward sloping best response function during *Period I*. The estimated slope for each player's best response function during these years, 0.84 for the United States and 1.06 for the rest of the world, shows that both players exhibited moderately aggressive production behavior during *Period I*.

During the years from 1975 until 1982, the Nash best response function of the rest of the world experienced a sharp increase in slope. This reflects a significant increase in the aggressiveness of production behavior in the rest of the world. A one ton increase in production by the United States would have caused the rest of the world to increase its production by 1.69 tons, which is a

60% increase in slope compared to *Period I*. This result is probably due to the fact that most of the producers outside of the United States were not subject to the ban of CFCs in non-essential uses. The effect may in fact be *under-estimated*, since Norway, Canada and Sweden banned the use of CFCs in nonessential uses during this time period.

The years just prior to the Montreal Protocol (1983–1987) are marked by another sharp increase in aggressiveness by the rest of the world. The estimate of CFC^{usa3} indicates that the rest of the world would increase its production by 1.78 tons, which is almost a two-fold increase in aggressiveness compared to *Period I* and an 13% increase compared to *Period II*. This result strongly suggests that producers outside of the United States did change their production behavior in anticipation of the Montreal Protocol, by displaying extremely aggressive production behavior. It may have been politically easier for European producers to increase production of CFCs, since many European governments were not as supportive of the Protocol as the USA, Canada, Norway, Sweden and Germany (Benedick 1991).

The parameter estimates on OIL_t indicate that an increase in the price of oil will result in decreased production of chlorofluorocarbons. Even though the parameter on OIL for the rest of the world is not significant, it carries the correct sign. The parameter on the demand variable (GDP_t) for the rest of the world is significant and carries the expected sign. This indicates that CFCs in the rest of the world are a normal good. The parameter estimate for the USA is not significant.[10]

To better demonstrate the changes in aggresiveness, Figure 2 shows a graphical representation of both players' best response functions for the three different periods. In order to demonstrate the changes and shifts of these reaction functions that are due to anticipatory production behavior, GDP_t and OIL_t are held constant at their sample mean. The continuous time dimension from 1958 until 1987 is now split up into three distinct time periods.

Figure 2 shows that while the United States' producers of CFCs became less and less aggressive as the negotiations for a global treaty approached, the rest of the world displayed more aggressive production behavior. This behavior gives strong reason to believe that producers of CFCs did change their production behavior in anticipation of the Montreal Protocol.

The interpretation of the production parameters is intriguing and may allow us to draw conclusions about the pre-treaty behavior of the USA and the rest of the world. Figure 3 shows the impact of the purely strategic changes in production behavior from *Period I* to *Period III*.

The net total increase in emissions due to strategic changes in behavior from *Period I* to *Period III* is about 200,000 tons of CFC for the 4 years preceding the Montreal Protocol. The strategic effect is possibly underestimated, since Canada, Norway and Sweden, who banned CFCs in non-

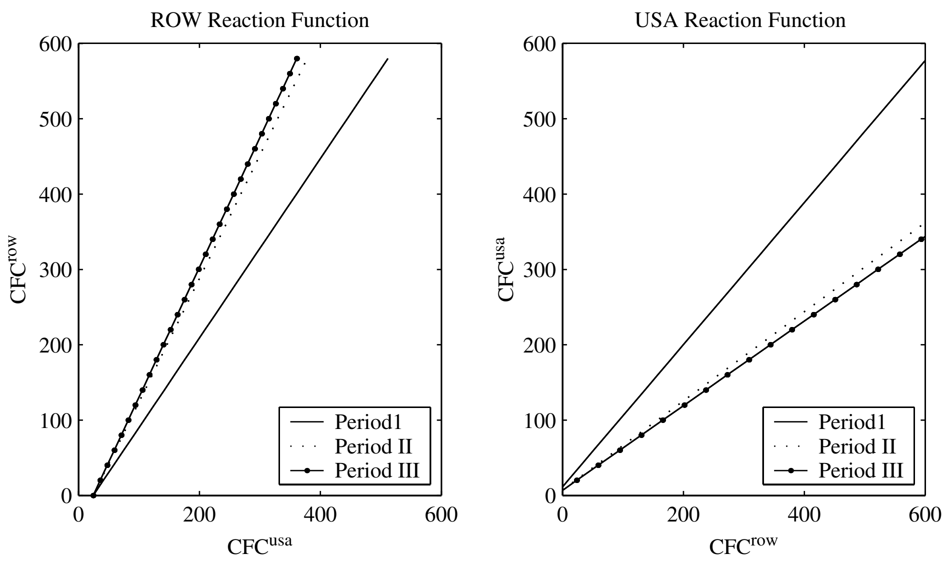

Figure 2. Reaction functions.

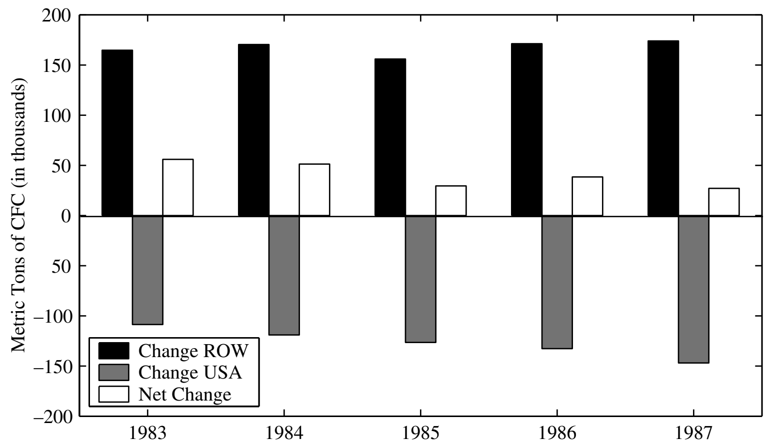

Figure 3. Impact of strategic behavior on the production of CFCs.

essential uses during *Period II* contained local subsidiaries of producers whose production is captured in the rest of the world data.

5. Conclusions

The intention of this paper was to test for possible anticipatory production behavior by chlorofluorocarbon producing nations prior to the Montreal Protocol on Substances that Deplete the Ozone Layer. In order to test for such behavior we assumed a simple period-by-period two-player

Nash–Cournot game between the United States of America and the rest of the world. The estimation results presented in Table II suggest that both players did exhibit a strong, asymmetric and statistically significant change in behavior during the years just prior to the Montreal Protocol in 1987.

US producers became less aggressive in the years preceding the Montreal Protocol, while producers in the rest of the world became more aggressive. The likely explanation for these behavioral changes have to do with the enactment of a unilateral control on the production of CFCs in the United States that followed quickly after the first hint in 1974 that CFCs could destroy atmospheric ozone. Less aggressive behavior by US producers during 1975–1982 apparently resulted from the ban on non-essential uses of CFCs in the United States. More aggressive behavior by producers in the rest of the world resulted as they moved to capture part of the market previously held by US producers. The empirical analysis strongly suggests asymmetric anticipatory production behavior.

The outcome of this research has important implications for the future development of policies regulating transboundary pollutants. If countries do anticipate International Environmental Agreements as suggested by this research nations who do not display anticipatory behavior will most likely be required to cutback a larger relative share, ceteris paribus. Therefore it will make these nations worse off from a welfare point of view in the long run. The scope of the empirical analysis in this paper does not allow us to estimate the overall impact of such behavior on global welfare. We estimate, however, that anticipatory behavior is responsible for a predicted increase of 200,000 tons of CFCs, which is roughly 1% of aggregate global CFC production from their invention until today.

The high level of aggregation of the data set does not allow us to study the exact nature of strategic behavior. Plant level production data would allow us to estimate a capacity withholding model, similar to the models used in the literature on electricity deregulation (e.g. Harvey and Hogan (2001), Joskow and Kahn (2001)). Our analysis suggests that producers in the United States had an incentive to withhold production capacity just prior to the Montreal Protocol, whereas producers in the European Union had an incentive to push production past economically profitable levels – in actuality or on paper. To separate this effect we would require plant or company level data, which is currently unavailable to us.

Future negotiations leading to International Environmental Agreements must take into account the incentives inherent in the process of negotiating treaties specifying cutbacks from a baseline year to avoid such changes in production behavior.

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Notes

1. Chlorofluorocarbons are also one of the largest contributors to the greenhouse effect.
2. The empirical literature on international environmental agreements is rather scant. Murdoch and Sandler (1997a) and Murdoch and Sandler (1997b) have examined the reductions of CFCs and sulfur dioxide before the reductions mandated by their respective international agreements went into effect. Congleton (1992) examined the impact of political institutional arrangements on international environmental regulation. No paper has addressed the issue of anticipatory behavior prior to an international environmental agreement that is the subject of this paper.
3. See Copeland (1990); Buchholz and Konard (1994), and Stranlund (1999). This literature is entirely theoretical; no attempt has been made to look for empirical evidence of changes in behavior prior to an international environmental agreement.
4. The Kyoto Protocol, for example, states cutbacks in terms of 1990 CO_2 equivalent emission levels.
5. We limit our analysis to CFC-11 and CFC-12, which are the two main sources of ozone depletion prior to the Montreal Protocol.
6. In both the theoretical and empirical literature on international environmental agreements, it is common to assume that decisions are made at the national level.
7. The countries, which contained at least one subsidiary of said producers produced approximately one sixth of the amount produced in the eight main countries listed and accounted for less than 15% of global production in 1986.
8. Country level production data is available after 1986 in United Nations Environmental Programme Ozone Secretariat (2002).
9. Since the date of the break from Period II to Period III is not quite as clear as the first break we conduct a predictive Chow test and confirm that a statistically significant break at the 1% level occurred in 1983.
10. Mason and Swanson (2001) provide an Environmental Kuznets Curve model of CFC consumption/emissions across countries and show that an in sample turning point does exist for some specifications. Since the EKC analysis is conducted in per capita terms, the sign of the parameter in this paper depends on where individual countries are with respect to income as well as the level of population since we use aggregate GDP. We further note that Mason and Swanson (2001) rely on estimated data from the usage of inputs, which is not available for the years covering *Period I*.

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