The Shaping of Environmental Policy: The Influence of Technological Innovation on Policy*

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I. Introduction

Existing research on the relationship between environmental policy and technology change has tended to argue that policy influences technological change.[1] A rare exception to this pattern is work by Irwin and Vergragt which makes explicit the reciprocal influence in this relationship through attention to both the social and technological characteristics of regulation-innovation interactions and social negotiation in regulatory and innovation outcomes.[2] However, Irwin and Vergragt's "interactive model of regulation-innovation" still tends to emphasize policy impacts on innovation to a much greater extent than the reverse (innovation impacts on policy) and has not been sufficiently developed to allow a systematic analysis of the shaping of regulatory policy by technological innovation. Existing conceptual models of the innovation-regulation relationship, including that of Irwin and Vergragt, tend to be prescriptively oriented[3] and/or focus only at the firm-level[4] despite the fact that industry and policy sector-specific factors have been found to play a significant role in the regulation-technological change relationship.[5]

This study uses the policy communities approach to policy analysis and the systems of innovation (SI) approach to technological change analysis to begin to empirically analyze the influence of technology on policy at the sectoral level. A network approach to technological innovation analysis, the SI model emerged to address recent changes in the nature and understanding of innovation processes. The influence of a technology innovation system network on the policy process through a policy network is expected to depend upon the characteristics of the actors common to both types of networks, the flows between the networks, and the nature of the links between the networks. Although the three aspects can impinge on each other, this paper will focus on exploring the first of these, actor characteristics, through a case study of policy processes in Canada associated with the automotive anti-knock fuel additive methylcyclopentadienyl manganese tricarbonyl (MMT) in the period from 1990 to 1998. MMT has been accused of interfering with functioning of the new generations of automotive air pollution control systems and debate about its toxicity is ongoing. This

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study hopes to contribute to the policy literature by better accounting for the reciprocal relationships in which policy is involved.

A. Policy Communities Reviewed

A policy community has been defined to include "all actors or potential actors with a direct or indirect interest in a policy area or function who share a common 'policy focus', and who, with varying degrees of influence, shape policy outcomes over the long run."[6] Policy communities have also been described as a "network of public and private entities that have a continuing stake in, and knowledge of, any given policy field or issue."[7] Mapping of policy communities in policy studies has been undertaken primarily to understand the relationships, or policy networks, among policy actors that develop around a particular issue of importance to the policy community. Policy networks are seen as patterns of relationships tying state and societal actors together in policy-making. Coleman and Skogstad dissect the structure of a policy network according to three characteristics: 1) organization of the state; 2) organization of business; and 3) the relationship between the two.[8] Key state characteristics include strength, autonomy, and capacity which help define the role played by the state. Level of organizational development determines the policy role played by industry and is reflected in representativeness, resources, autonomy, and policy capabilities.

B. Systems of Innovation: An Overview

A system of innovation (SI) is defined as "a network involving individual and collective processes of searching, learning, and selection among different innovation opportunities."[9] A SI may also be seen as "elements and relationships which interact in the production, diffusion, and use of new, and economically useful, knowledge."[10] Elements of the system can work together to reinforce or constrain processes of learning and innovation.

SI can involve multiple types of interaction including learning and knowledge, economic (market transactions, public funding, and financial system), social (learning, movement of personnel), and political and policy-related. Flows of information, knowledge, ideas, skills, material, finances, capital, technology, personnel, and regulation move between elements of the SI. Links between the structures can be characterized according to quality (e.g., strong or weak), quantity, asymmetry, interdependence, timing, frequency, and duration. Relationships will "often involve elements of power and hierarchy, and the direction of innovations will reflect who is the dominating party."[11]

Systems of innovation approaches have been used to analyze innovation processes at different levels (politically and geographically) and from different angles (technologically and sectorally). These include the national system of innovation, the regional innovation system, the local innovation system, the technological system of innovation, and the sectoral innovation system. Despite difference in emphasis, these approaches are generally asserted to be complementary and not mutually exclusive.

In particular, the sectoral innovation system (SIS) model developed by Breschi and Malerba will be used here as the framework for analysis because it is consistent with the sectoral-level of the policy network analytical framework.[12] Malerba defines a sectoral system of innovation and production as "a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products."[13] Actors "interact through processes of communication, exchange, cooperation, competition and command, and their interactions are shaped by institutions (rules and regulations)."[14] The SIS model is framed by the following elements: products; agents or actors; knowledge and learning processes; basic technologies, inputs, demand, and key links and complementarities (including links to related sectors, convergence of products that were originally separate, emergence of new demand); mechanisms of interactions within and outside firms (market and non-market); institutions (including standards and regulations); and processes of selection and variety creation.

Because this study is centred on a particular set of technologies (automotive tailpipe emission controls) within the automotive sector, it could be argued that the technological system (TS) model may be more appropriate than the SIS framework. A TS has been defined as "a network of agents interacting in a specific *economic/industrial area* under a particular *institutional infrastructure* or set of infrastructures and involved in the generation, diffusion, and utilization of technology."[15] However, Edquist suggests that one form of SIS are TS in which generic technologies or "technology fields" set the boundaries of the system, the other form being defined by a particular industrial area.[16] Given that the various approaches to SI analysis (national, regional, local, sectoral, technological) are asserted to be complementary, overlap between these frameworks can be expected. Due to its expected ability to facilitate correlation and analysis with the policy network approach at the sectoral-level and to answer a subset of questions from within the framework (e.g., within SIS, consideration of a particular set of products rather than the full range of products within a sector), the SIS approach has been chosen over that of the TS here. Although the SI approach tends to emphasize innovation over other phases of technological development (e.g., invention, diffusion, decline), because of connections to, and overlap with, the TS approach, other stages of technological change are accommodated within the framework used in this study.[17]

II. The MMT Policy Process and Policy Network: 1990 to 1998

In the late 1970s, MMT began to be added to automobile gasoline in Canada as an alternative to tetraethyl lead (TEL) for boosting gasoline octane ratings and reducing engine knock to help ensure fuel burning without engine damage.[18] Environment Canada announced intentions to introduce a bill to regulate MMT in gasoline in 1993 and did so in 1995. In June 1997, the federal Manganese-based Fuel Additives Act came into force which prohibited the importation of, and interprovincial trade in, MMT.[19] In July 1998, this ban on trade in MMT was effectively rescinded by the Canadian government.

The MMT policy process primarily pitted Environment Canada, Transport Canada, the governments of British Columbia and Ontario, and the Canadian auto industry represented primarily by the Canadian Vehicle Manufacturers' Association (CVMA) and the Association of International Automobile Manufacturers of Canada (AIAMC) against the Canadian petroleum refining industry represented primarily by the Canadian Petroleum Products Institute (CPPI), the manufacturer of MMT (Ethyl Petroleum Additives, Incorporated and its Canadian subsidiary, Ethyl Canada), and the remaining provinces led by Alberta. This section provides a brief chronology of the policy process area and examines the policy actors of significance in shaping the MMT policy process in

Canada with a focus on the time period from 1990 when Canadian gasoline regulation prohibited leaded gasoline (to allow proper operation of the catalytic converter) thus requiring alternative means to enhance octane levels to 1998 when the Canadian MMT trade ban was lifted.

Leading up to 1992, the introduction of the Canadian Environmental Protection Act (CEPA) in 1988 ultimately placed significant restrictions on the federal government's ability to regulate MMT, the Canada-U.S. Free Trade Agreement (FTA) in 1989 further integrated the auto industry in the U.S. and Canada (originally integrated by the 1965 Canada-United States Automotive Products Trade Agreement, or Auto Pact), and the start of the U.S. Auto/Oil Air Quality Improvement Research Program (AQIRP), an auto manufacturer and oil industry initiative, began to increase attention to the importance of fuel composition in automotive air pollution reduction. In 1990, Canada's final ban on lead came into effect, the Canadian Council of Ministers of the Environment (CCME) endorsed a federal nitrogen oxides (NOx) and volatile organic compounds (VOC) management plan which formed the basis of future federal actions on cleaner gasoline and stricter vehicle emission standards for the mid-to-late 1990s. Also in 1990, the U.S. amended its Clean Air Act (CAAA) to require reformulated gasoline (RFG) in 1995. This U.S. action bore heavily on the Canadian MMT process with its increased focus on fuel as a source of auto emissions reduction as well as concerns about dumping of low quality fuels in Canada and of the Canadian refining industry not keeping pace with technology change to remain competitive in the international market. This issue was linked to increased interest in MMT removal from Canadian automotive gasoline and provided an opportunity to highlight MMT as a significant difference between U.S. and Canadian vehicle fuel formulation, to contrast the difference in innovation efforts made historically by the auto and refining industries in addressing auto emissions, and to emphasize the need for common U.S. and Canadian fuel given the North American auto industry integration. The 1990 U.S. CAAA also introduced requirements to install OBD-II systems in motor vehicles (beginning in 1994 model year). This requirement affected Canadian automakers, given the North American integration of the auto industry and the Canadian government policy of auto emissions standards alignment with the U.S., and, in turn, the MMT policy process given the possibility of MMT-interference with these OBD systems argued by automakers.

From 1993 through 1994, critical contextual changes took place which had direct and significant bearing on the shaping of the MMT policy process. Environment Canada began concerted efforts to encourage the Canadian auto and oil refining industries to resolve the MMT issue without government intervention around 1993. In 1994, the Agreement on Internal Trade (AIT) and North American Free Trade Agreement (NAFTA) were established which bore most significantly on Canadian MMT policy-making (due to the proposed law's trade restrictive aspects), the second generation of on-board diagnostics technology (OBD-II) (around which the MMT auto impact debates were centred) began to enter the marketplace in new vehicles, Health Canada produced a report on health risks associated with MMT that effectively prevented use of CEPA as an MMT regulation tool (MMT use in gasoline was found not to pose a health risk to Canadians), Canadian automakers submitted confidential data to the federal government indicating concerns about negative effects of MMT on autos (increased HC emissions, oxygen sensor deterioration, catalyst plugging and malfunction, and spark plug misfire.[20]), and the Canadian refiner and auto industries failed in attempts to reach agreements related to MMT.[21] Note that automaker difficulties in meeting the OBD-II requirements by the mandated deadlines resulted in regulatory relief from EPA. In March 1995, EPA stated that "given the newness and considerable complexity of designing, producing, and installing the components and systems that make up the OBD system, manufacturers have expressed and demonstrated difficulty in complying with every aspect of the OBD requirements."[22]

The core period of very active and direct Canadian MMT policy-making was from 1995 to 1998. The most significant events of 1995 included introduction of Bill C-94 by Environment Canada (at least in part spurred by indications from automakers in late 1994 and early 1995 that they intended to disconnect emissions system warnings and void warranties on emissions control hardware and concerns about problems meeting terms of a Memorandum of Understanding, MOU, to install OBD-II), deferral of the implementation of more stringent auto emissions regulations (including requirements for OBD-II) due to the continued existence of MMT in gasoline, and a court-ordered U.S. Environmental Protection Agency (EPA) policy reversal regarding MMT which allowed its use in the U.S. (though not in federal or California RFG) in unleaded gasoline up to a concentration of up to 8.3 mg Mn/L (less than half the limit of a Canadian General Standards Board, CGSB, voluntary recommended standard of 18 mg Mn/L established in the late 1970s)[23] and thus undermined the harmonization argument of proponents of the Canadian MMT bill.[24] Also prominent in this year was the endorsement by the CCME of the report by the Task Force on Cleaner Vehicles and Fuels which did not address MMT directly but gave momentum to the focus on fuels as a source of motor vehicle emissions reduction, recommended more stringent vehicle emissions standards and harmonization with U.S. auto emissions standards, and generated controversy by virtue of the fact that MMT was not incorporated into the Task Force work. [25]

The dissolution of Parliament in early 1996 and a cabinet shuffle caused Bill C-94 to drop off the order paper. By April 1996, the bill was re-introduced as Bill C-29 (unchanged from its C-94 form), at 3rd reading. At the federal level, the Department of Foreign Affairs and International Trade (DFAIT) raised concerns about international trade obligation conflict with the bill and trade tensions with the U.S. Provinces in opposition to the bill, led by Alberta, raised concern about the bill contradicting NAFTA and the AIT.

The most notable events of 1997 included the passing and going into effect of the Manganese-based Fuel Additives Act prohibiting import and interprovincial trade in MMT, the launching of Ethyl's $250 million NAFTA Chapter 11 claim against the Canadian federal government, and the initiation of Alberta's challenge (prompted by the refining industry) of the federal government under the AIT. In the latter half of 1997, Transport Canada issued new auto emissions control regulations for vehicle model year 1998, a key policy action in this issue area because proper functioning of OBD-II, according to automakers, depended on MMT-free fuel.

The collapse of the MMT law marked the year 1998. In June, the AIT's dispute resolution panel ruled against the "interprovincial" trade portions of the MMT law and the NAFTA Tribunal ruled two weeks later on jurisdiction in the MMT case (finding that it did have jurisdiction in the case) but also went beyond that decision to address Canada's defence related to the scope and application of NAFTA, finding them to be, at first review, inadequate.[26] In July, the ban on trade in MMT was effectively repealed by the Canadian government (a regulatory change removed MMT from the Schedule listing substances to which the ban on trade applied).[27] Reflecting automaker frustration with inter-industry efforts to change fuel formulations to meet their needs, in 1998, the World Wide Fuel Charter was introduced by the world's automakers (at this time the Canadian automakers also abandoned the CGSB unleaded gasoline standards setting process[28] and focused instead on promoting the World Wide Fuel Charter, a global auto industry effort to specify automotive fuels which specifically recommended that the "use of any metal-based additives" such as manganese be avoided for potential health reasons and catalyst damage[29]). Furthermore, Canada actively participated in the development of the United Nations Economic Commission for Europe (UNECE) Agreement Concerning the Establishing of Global Technical Regulations for Wheeled Vehicles (Global Agreement) process on technical standards for autos which was established in 1997 (and concluded in 1998) to facilitate international regulatory harmonization for motor vehicles.[30]

A. The State

The Federal Level

In moving the MMT policy forward, Environment Canada, specifically, and the federal government, more generally, drew upon a number of its capacities to make policy. First, the ability to regulate interprovincial and international trade was used with parallels drawn to the Motor Vehicle Safety Act's regulation of new vehicle emissions in attempts to defend its choice of policy mechanism and fend off questions including those about jurisdiction and constitutionality. Second, Environment Canada, with the participation of other federal government entities, made use of its ability to conduct a relatively closed decision-making process (which included consideration of confidential auto industry technical information submitted by the automakers) to exercise greater control over the policy process. Third, Environment Canada emphasized its significant role as an international representative for the provinces and for Canada as a whole in dealing with transboundary air pollution from the U.S., but also to ensure that Canada showed progress towards meeting its international air pollution commitments. This helped increase its strength in the broader air pollution policy arena in which the MMT issue was embedded.

However, as a policy-maker, Environment Canada was dependent upon, not just the information supplied by the automakers (whose claims to confidentiality perhaps contributed to the government's decision to conduct a closed policy process thus increasing opponents' criticism of the bill), but also its support along with that of the Senate Standing Committee of the Environment and Sustainable Development, the provinces of BC and Ontario, and the advocate sector who helped mobilized public support. The department found further, though perhaps relatively weaker, support interdepartmentally in Transport Canada (who also relied heavily on automakers and refiners for information related to transport emissions) and Health Canada which was, however, countered to some extent by opposition to the bill from Natural Resources Canada and DFAIT. Such intra-governmental conflict and jurisdictional overlap as well as inter-governmental tensions weakened Environment Canada on this issue. Environment Canada's position was further eroded by its unwillingness and/or inability (whether technical, financial, or other) to generate studies of its own on the MMT issue and reliance on the review of existing health and motor vehicle impact studies conducted by, among others, the EPA, World Health Organization, and Health Canada. These weaknesses ultimately contributed to the demise of the MMT law when the AIT dispute resolution panel ruled against the law's interprovincial trade portions.

The Provincial Level

Provinces opposed to the MMT bill, eight in total (a clear majority of Canadian provinces with Alberta leading the charge), made use primarily of inter-governmental agreements and understandings, but also of industry support and jurisdictional claims in attempts to slow the momentum of the proposed law. Appealing to federal-provincial norms of cooperation which were re-emphasized through the Canada-wide Environmental Accord and the work of the CCME Task Force on Cleaner Vehicles and Fuels, these provinces argued for a more inclusive policy process, in particular asserting that the MMT issue should have been routed through the CCME Task Force work on vehicles and fuels. Although late in the process (the law had already been passed), to greatest effect, provinces in opposition to the MMT bill, drew on mechanisms in the newly created AIT to ultimately reverse the MMT law. Timing of this agreement, in combination with that of NAFTA and the concurrent pressure applied by Ethyl through NAFTA, provided a policy-capability, in 1995, previously unavailable to the provinces. Weakening provincial opponents' influence over the MMT policy process were, however, a limited ability to generate their own information related to the issue and a lack of access to confidential data submitted by motor vehicle firms to select supportive governments.

Provincial proponents of the bill were few in number (BC and Ontario) but economically significant in Canada, recognized environmental leaders among the provinces at the time, and the location of the most significant smog problems created by local and regional auto emissions. Provincial supporters of the MMT bill had in their coalitions, the auto industry and most prominently the federal government, especially Environment Canada and Transport Canada.

B. Industry

The Automotive Industry

Although not strictly of a high level of organizational development (representation through a strong, autonomous organizational system), the auto industry did present the state with an attractive opportunity as a participant in MMT policy-making through two aspects of its character. First, a cohesive position was formed on the issue with the CVMA, AIAMC, and individual firms unified in their support for the bill. Second, the auto industry had a significant role in policy implementation -- not the MMT policy, but that of further tightened new vehicle emissions regulations that came out in 1997 for auto model year 1998, essentially the "shadow" policy of significant importance in this issue area due to automaker insistence that such standards could not be met unless MMT was removed so OBD-II and catalytic converter systems could function properly.

Furthermore, as a critical provider of technical information to the state in the policy process, the auto sector increased its influence in the policy network.

A relatively long historical relationship with Transport Canada due to auto emission standards regulation and MOUs was one of a number of links to federal state power that benefited the auto industry in the MMT policy process. The existence of this relationship had critical significance as it allowed automakers to leverage their position by tying the need for restrictions on MMT to their ability to successfully meet newly proposed auto emission standards introduced by Transport Canada. Ties to Environment Canada in voluntary pollution prevention MOUs similarly helped the auto industry's position in MMT policy-making over the refining industry. Links to the state federally, with Transport Canada and Environment Canada, and provincially, with Ontario, as well as advocate sector and public support gave the auto industry diverse bases of power on which to draw in advancing the MMT bill. Outside of Canada, but also significant given the auto sector's global nature and importance to Canada's trade balance, Canadian automakers drew on support from U.S. counterparts, international automaker agreements, and the EPA's position on MMT (resistance to its use).

On the spectrum from policy advocacy to policy participation, the auto industry role was arguably more of a participant than other industry actors in this policy network since it moved beyond influence and competition to successfully push the federal government to intervene in this issue and develop restrictions on MMT (rather than continue to allow the auto and oil sectors to try to resolve the issue themselves). Formal access to MMT policy-making was limited by the fairly closed nature of decision-making at the highest levels of the federal government but the auto industry was able to infiltrate this process to some extent through its ability to provide relevant technical information of a claimed confidential nature. However, the claimed confidentiality of this information weakened the automakers in that it raised questions about the data's ability to stand up to broader scrutiny.

As suggested by Hill and Leiss and Soloway, an additional aspect of influence, auto manufacturers were perceived to be less biased and have less vested interests in regulating MMT than refiners and Ethyl (given its manufacture of MMT's predecessor, the controversial anti-knock additive, tetraethyl lead).[31] Credibility and influence were further gained through the ability to mobilize broad public support, especially with environmental and health advocate groups joining the auto sector coalition.[32]

The Oil Refining Industry

Like the automakers, the refiners came to the MMT policy process with a relatively unified voice. However, unlike the auto sector, refiners did not have a significant historical relationship with those in the federal government whose interests were most served in pushing the MMT bill. This likely made more difficult attempts at access to the closed policy process of the federal government and prevented, unlike the confidential data presented by the auto industry, more serious consideration of the MMT automotive study the refiners (under CPPI) had conducted themselves. Such a lack of consideration was likely also based on the assumption that refiners were limited, relative to the auto industry, in their understanding of the technical aspects of auto emissions controls. Economic weakness relative to the auto industry also undermined the refiners possibly reducing their capabilities to influence policy. This weakness, however, was also used as an argument to suspend the MMT bill as it was argued to be expected to cause additional hardship to the industry. Ultimately, the refiners were confined to a policy advocacy role (influence and competition in policy-making through information generation, support mobilization, and cohesion) but were given strength by coalitions, most significantly, with sympathetic provincial governments concerned about provincial economic health and, through that support, accessed the use of the AIT to bring down the policy.

Ethyl Corporation

The links of Ethyl Corporation, the manufacturer of MMT, to state power were limited and those that did prove useful were fairly indirect. The economic and thus political importance of Ethyl, a single foreign firm, paled in comparison to the other economic interests with which it was competing in this policy issue area rendering its direct influence on Canadian policy-making through access to the Canadian government relatively weak. Even in the U.S., Ethyl's attempts to put pressure on Canada through the U.S. government failed to elicit desired support from the U.S. government. Ethyl's access to the Canadian government and ability to make itself heard and attempt to shape the MMT policy came through Senate hearings and through the firm's coalition with Canadian refiners who, in turn, made use of relationships with provincial governments. Through its Canadian subsidiary, Ethyl also applied pressure on the policy process through the judicial system (an approach to influencing policy with which it was familiar and had success in the U.S.) based on questions of federal jurisdiction and constitutionality of the MMT law. Like the refiners, however, Ethyl was confined to a policy advocacy role.

Capacity to influence policy for Ethyl came most prominently from the timing and existence of NAFTA's Chapter 11 and the associated weight of Ethyl's NAFTA challenge of the Canadian government. However, this was actually highly uncertain capacity at the time given that, like the AIT dispute resolution panel MMT case, this was also the first case of its kind. This capacity was enhanced by Ethyl's legal capabilities and general political process experience (although within the U.S. system), having struggled in the U.S. with EPA over this issue within both regulatory and judicial processes for almost 20 years by the time the MMT law was passed in Canada. Ethyl's policy-making capacity was also heightened by Ethyl's technical capabilities, having conducted its own studies on MMT (both to support its own interests and as required by the EPA in the U.S.) and, as the manufacturer of MMT, its significant inherent technical knowledge of the fuel additive.

Inter-Industry Relationships within the Policy Network

The issue of who should innovate or diffuse technology further for auto emissions reduction and control the direction of innovation/diffusion was a significant tension between automaker and refiner interests. Because automakers were having a difficult time with development of the OBD-II technologies, it was in their interest to minimize potential obstacles to successful operation of these systems and to shift at least part of the blame for problems encountered. Refiners, however, were concerned about losing control of their own processes of, and decisions surrounding, technological innovation and diffusion and, in so doing, bear economic costs that might otherwise be borne by the auto sector. This tension contributed to the difficulties in resolving the MMT issue without government intervention. Furthermore, in combination with the tightening of auto emissions standards (for 1998 and 2001 model years) and the changing perspective of vehicles and fuels as an integrated system, this tension served to intensify conflict between automakers and oil refiners.

Inter-industry tension around technological change related to the MMT policy process was reflected in three issues. First, automakers asserted that they had already spent millions of dollars on engine technology and emission control systems innovation to achieve significant emission reductions over the prior twenty years and that fuel changes were essential for further reductions.[33] Furthermore, the auto sector argued, the technology to provide octane using alternatives to MMT already existed and that for the refiners, it was not a question of having to develop new technology.[34] Second, automakers interests in fewer additives and reduced concentrations of additives ("simpler fuels") to make it technically easier to design systems and to increase their reliability were seen to conflict with refiners interests in producing gasoline with lower octane for cost reasons and environmental reasons ("octane…requires more energy, more severity, additives, et cetera").[35] Third, another divide between refiners and automakers was that of addressing auto emissions for new vehicles as opposed to those already in use. In answer to arguments from the auto industry (and government proponents of the MMT bill) that fuel changes could have an immediate emissions reduction impact on all in-use vehicles (including older vehicles which tend to be higher polluting given that they operate without the latest and most stringent emissions controls of new vehicles), refiners suggested, in the interest of pushing the cost burden elsewhere, that scrappage programs for older vehicles should be accelerated, especially for Canada's smoggiest regions.[36]

III. The Sectoral Innovation System for Automotive Exhaust Emissions Control in the 1990s: Focus on Major Actor Characteristics

The network around which technological change affecting automotive exhaust emissions control in Canada revolved in the 1990s included, most prominently, the automotive and petroleum refining industries. Although elements of the SIS analytical framework include products, actors, learning processes, basic technologies, mechanisms of interaction, institutions, and processes of selection/variety creation, the focus here will be on examining the auto and refining sector actors including their technologies and sectoral features that shape actor influence within the network. Note that although a comprehensive analysis of the SIS shaping automotive exhaust emissions control is not being conducted in this study, preliminary review of evidence suggests that such a network does exist. For example, the Partnership for a New Generation of Vehicles (PNGV) announced in 1993 as a 10-year program, a government-industry program which operated under the U.S. Council of Automotive Research (the research umbrella for the Big Three automakers in the U.S.) was a collaborative initiative which included emissions control aspects.[37] Some Canadian companies were involved with the PNGV and a parallel Canadian Council for Automotive Research (CANCAR) serves as an R&D consortium of the Big Three automakers in Canada.[38] In addition, the World Fuel

Charter and the UNECE Global Agreement, although not strictly technological R&D collaborative initiatives, did seek to influence technological change through standardization and diffusion. This auto sector technological network draws in the oil refining sector as well with the U.S. Auto/Oil AQIRP which ran from 1989 to 1996 "to better understand the vehicle and fuel synergistic effects on emissions and resultant air quality"[39] and involved a collaboration of U.S. auto and oil industries.[40]

Although not examined in detail here, in addition to activities of the private sector around automotive exhaust control, the Canadian government played a supplementary, though lesser and less direct, role in this area and tended to have a greater focus on the longer-term development and implementation of alternative fuel and vehicle technologies which had less direct links in the 1990s to the policy area of interest. As a reflection of the Canadian government's interest and role in supporting activity in this area, the CCME Task Force on Cleaner Vehicles and Fuels noted (in 1995) that "There are…important economic development opportunities for Canada if a proactive (aggressive) market stance is taken. Technology development programs by Canadian manufacturers over the past fifteen years, often with funding from federal and provincial governments and the fuels industry, have resulted in significant early production of alternative fuel vehicles in Canada. Also, Canadian companies manufacture a wide range of alternative fuel products such as complete refueling station installations, advanced gaseous fuel carburetion systems for gasoline and diesel engines, conventional and lightweight fuel tanks and, for the longer term, fuel cells, hydrogen electrolyses and advanced batteries. These leading edge products are marketed in Canada and many other countries. Also, several unique vehicle projects have been developed in Canada, such as Chrysler's new liquid fuel propane vehicles and 'ULEV' natural gas vehicles, natural gas transit buses, and Ballard's hydrogen-powered fuel cell bus."[41]

A. The Automotive Industry

Actor Competencies and Sectoral Features

The early 1990s were economically difficult times for Canada with a recession through at least 1992. With 1996 a turnaround year, by 1997, Canada returned to stronger economic times, helped largely by growth in international trade.[42] Although automakers had concerns about a shrinking new vehicle market by the mid- to late-1990s, Canadian vehicle production levels did remain reasonably steady during this period due to production for export to the U.S. unlike refiners who appeared to have felt more keenly the economic difficulties of the early 1990s and been relatively economically more fragile than the auto sector at this time with a consolidation of the industry, layoffs, and shut-downs in the prior decade.

The economic importance of the Canadian auto industry in Canada is significant. Beyond the importance of the industry with respect to share of gross domestic product (largest single contributor to manufacturing GDP), employment (approximately 5 percent of employment in Canada), export (approximately 20 percent of exports), and investment (although the Canadian automotive industry invests little in R&D relative to its U.S. counterparts, it was the largest investor in the manufacturing sector in 1997), its links to other parts of the Canadian economy are extensive; the sector's contribution to the economy is much larger when these linkages are taken into account.[43] The auto industry is a significant consumer of steel, iron, aluminum, copper, rubber, plastics, textiles, glass, chemicals, machine tools, machinery, electrical products, and semi-conductors.[44] It has been the largest single purchaser of a number of processed raw materials and fabricated products.[45] In addition, it encourages development of high technology goods and services (micro-electronics, engine controls, on-board diagnostic computers, new materials, and alternative engines) and new manufacturing processes.[46] Major Canadian exports of goods through most of the 1990s were in motor vehicles and parts, machinery and equipment, and forest products (with petroleum products fourth in rank order).[47] This indicates the relative economic and thus political significance of the auto sector (also relative to refining) with respect to trade during this time period.

Despite the Canadian auto sector's economic significance, Canada's share of automotive R&D is relatively small with little attention to automotive exhaust emissions control. The Canadian auto industry tends to be involved more in technology adoption and diffusion rather than development.[48] Canada's automotive assembly R&D in the early 1990s tended to be process-related and plant-specific.[49] This continued to be the case into the late 1990s and was attributed to foreign ownership and resulting structural factors in the auto industry.[50] The structure of the Canadian auto industry is defined by several factors including Canada's proximity to the world's largest auto market (the U.S.), the high level of foreign ownership in the industry (the sector has the highest foreign direct investment concentration in the economy), and the oligopolistic nature of the industry which is dominated by the Big Three auto firms which account for the majority of production, sales, and employment.[51] R&D expenditures by Canadian independent parts firms focus on niche product development (hydroforming, magnesium parts, fuel cells, continuously variable transmissions, and aluminum vehicle parts) and on production processes.[52] There are also research institutes performing related work, mainly on alternative fuel technology.[53] Despite a relative paucity of Canadian auto R&D, niche opportunities have existed and been exploited in Canada by the Big Three (GM on alternative fuels, Ford on aluminum technology, Chrysler with the University of Windsor on alternative fuels and design).[54] Even in 1989, despite being part of an integrated North American production system, Canadian activities were largely restricted to assembly and sales, with most R&D carried out at corporate headquarters locations in the U.S., Europe, or Japan.[55] Related to automotive product (as opposed to process) technology change (including automotive exhaust control), the U.S. tends to have had the most influence in Canada, given the integration of the market across the Canada-U.S. border and the tendency of the Canadian government to harmonize with U.S. automotive emission standards.

Influences on R&D in the U.S. auto industry include industry structure and competition. First, the highly concentrated and oligopolistic industry structure establishes high barriers to entry which means that if an independent innovator develops an innovative idea for a vehicle, major vehicle component, or manufacturing process, they must convince at least one of the existing few manufacturers of the innovation's value because it is unlikely that they could produce the innovation themselves. The industry structure also influences the choice of strategy to attract replacement demand. This strategy is generally one of incremental and styling model changes over riskier fundamental product changes. Second, various bases of competition are seen to exist in the auto industry; technical performance (including fuel efficiency and safety), reliability, style/design, cost (initial and operating), brand name, and environmental leadership.[56]

Given the significance of the contributions to the economy of the Canadian auto industry as noted above, this sector has the potential to wield substantial political power within Canada and in this way further its technological interests. In the mid-1990s, Gayle and Graves suggested that auto intra-industry collaboration was on the rise in the auto sector, some of which may have been opportunistic alliances to influence policy-making in the industry.[57]

The Nature of the Technology Changes

Related to the policy issue area of interest here (MMT and automotive exhaust emissions) in the 1990s, the most important technological changes emerging from within the auto industry around which this technology network was centred were twofold. First, the catalytic converter system was refined to address start-up emissions and to improve resistance to catalyst degradation from high temperatures and from lead, sulphur, and phosphorus (found in gasoline and lubricating oils).[58] Although modern development work on the catalytic converter originated in the 1950s and 1960s, the device was not commonly found on new automobiles until the mid- to late-1970s.[59] Oxidation catalytic converters were the first prominent iteration of the catalytic converter and were used from approximately the mid-1970s to 1980.[60] The oxidation catalytic converter system reduced HC and CO emissions and required the availability of unleaded gasoline. A "dual" catalytic converter system was subsequently developed to control HC, CO, and NOx.[61] The dual catalytic converter system later evolved into the three-way catalytic converter (TWC) system where one catalyst formulation simultaneously controlled HC, CO, and NOx. These concurrent reactions were possible only if the air-fuel (A/F) mixture was maintained within a very specific range made possible only with computer control of fuel metering using a feedback control system with an oxygen sensor indicating the adjustments needed for the fuel supply to maintain the specified A/F mixture.[62]

Second, OBD-II systems were developed for implementation in the mid-1990s in the U.S. and the late-1990s in Canada. The first on-board diagnostic systems (OBD-I) were developed by automakers in the late 1970s and early 1980s as electronic systems began to replace mechanical systems in vehicles. Because OBD-I systems had been developed individually by each manufacturer, unique systems and signals were developed specific to a given auto manufacturer (and even some models from the same manufacturer). There was a strong need for standardization to monitor the same components, use the same computer language, and have the same criteria for evaluating the systems and indicating problems to drivers and service technicians. OBD-II, in addition to standardization, involved an expanded set of capabilities from OBD-I as well as moving beyond detection of failure of system components to detection of deterioration. The research and development for both the catalytic converter and OBD-II technologies, which has affected the Canadian automakers in the 1990s, has been concentrated within the U.S. auto industry.

The significant contribution of both of these technologies to auto tailpipe emissions control and the relationship between them (the need for computer controls, later developed into OBD systems, to allow concurrent control of HC, CO, and NOx in the TWC) meant that the auto industry had considerable interests in seeing them operate optimally, in part, through compatible fuels. Such fuel formulations were seen ideally to have low sulphur content and no MMT.

B. The Oil Refining Industry

Actor Competencies and Sectoral Features

In the mid-1990s, the refining industry in Canada was highly concentrated with more than 50 percent of the refining capacity controlled by the three largest refiners (Imperial Oil, Petro-Canada, and Shell Canada) who are major integrated companies (involved in exploration and extraction, refining, as well as retail sales).[63] At this time, Canadian-owned refineries constituted 44 percent of refinery capacity with 35 percent U.S.-owned, and 21 percent foreign ownership other than the US (primarily European).[64]

Like the auto industry, the refining industry is of significant economic importance in Canada. It is a net exporter, a major contributor to GDP, and a major employer.[65] The refining industry has a significant role in Canada's wealth and security (unlike the U.S., Canada is self-sufficient in petroleum products).[66] The petroleum refining industry has been asserted to be a "strategic infrastructure industry" in that it provides essential inputs to other major businesses such as petrochemicals, transportation, power utilities, chemicals, chemical products, agriculture, and mining. Canadian refining is a mature industry with little demand growth and low profitability.[67] The industry is highly competitive, very capital-intensive, and has a strong domestic market focus (more than 90% of gasoline sold in Canada is domestically refined).[68] Process innovation is of primary importance in the refining industry as the product is relatively undifferentiated and cost is a key competitive-basis. This, therefore, requires the need for process innovation to gain competitive advantage through cost reduction.

Events from the 1970s led to extensive rationalization of the refining industry in Canada from this time through the 1990s. By the year 2000, there were 18 gasoline-producing refineries, down from 40 in the 1980s and 58 in the 1970s.[69] Consolidation of the industry resulted from increased competition and a significant drop in gasoline demand due to a weak economy and high crude oil prices following oil price shocks in the 1970s. In addition, in the early 1980s, automotive fuel efficiency increased and natural gas and electricity competed more strongly with heating oil causing its demand to fall. However, demand for refinery products began to climb again after 1987 and through the 1990s.[70] By the mid-1990s, the oil industry was recovering. Economic weakness from the late 1980s into the 1990s likely contributed to the relatively limited amount of R&D in the Canadian refining sector.

Decline in high quality, light crude oil, a worldwide phenomenon, affected Canadian refineries into the 1990s. Light crude oil "is the crude which Canada's refineries were built to process, high quality oil that yields large proportions of the transportation fuels we use."[71] In Canada, this decline began in the mid-1970s, with heavy grades of oil, synthetic oils from oil sands, enhanced production from older fields, and expected production of new light crude reserves offshore and in the Arctic making up losses in light crude. These alternatives, however, were more costly to produce and more difficult to refine. As a result, there was increased pressure for process-related technological change to more efficiently accommodate different grades of crude oil and to increase the yield from conventional light crude.

Although the Canadian refining sector is not integrated with the U.S. as is the case for the Canadian auto industry, policy and refining industry changes in the U.S. (e.g., RFG requirements, ban on MMT until 1995) served, not only as an interesting contrast to the unfolding of events in Canadian refining, but also affected the need for such change in Canada (due to fuel specifications, trade competition, and auto industry integration). In the 1990s, many U.S. refineries implemented new technology as a result of RFG requirements in the early 1990s and to increase profits by processing heavier crude when cost differentials in light and heavy crude made it profitable to do so, a move not made by Canadian refineries due to light sweet conventional crude oil being more readily available from Canadian suppliers and the difference between prices of Canadian light and heavy crude oil being set by the federal government rather than the market[72] U.S. refineries were thus better positioned to process the cheaper, heavy crude oil and to meet octane requirements with the removal of lead from gasoline.[73]

Technological change within the refining industry during the 1990s was essentially a case of technology diffusion with concerns about the associated cost of implementing new technology (given the capital-intensity of the industry); technology change in the industry was not a matter of technological availability (or, technology innovation) to meet the pressures to which the industry needed to respond.[74]

The Nature of the Technology Changes

Many of the most significant technological changes in recent years in the refining industry took place in the 1950s and 1960s with subsequent incremental improvements in the following decades. Areas of focus with respect to technology change in the 1990s were catalysts (for one of the main processes in refining, fluid catalytic cracking) and process instrumentation and monitoring technologies, all process-related changes. Environmental requirements in Canada and the U.S. which addressed automotive fuel specifications were seen to contribute to refining technology change in the 1990s.[75] The main initiatives in Canada included: 1) the handling of heavy crude oil and oil sands crude/synthetic crude oil; 2) maintenance of octane levels given the phase-out of lead and subsequent restrictions on MMT; 3) reductions in summer gasoline volatility, sulphur, and benzene; and 4) responding to the U.S. CAAA 1990 requirements for RFG as a result of concern about fuel dumping of lower quality fuels from across the border.[76]

Despite these initiatives, the Canadian refining sector does not appear to have conducted a significant amount of R&D itself and seemed to resist a role in technology change, especially product-related, given the associated capital costs to be incurred at a time when the sector was just coming out of a period of significant industry-wide rationalization.

IV. Analysis of the Interaction of the MMT Policy Network and Automotive Exhaust Emissions Control Sectoral Innovation System: Common Actor Influence

To begin to analyze the influence of technology on policy-making through an exploration of the characteristics of actors that are common to both policy and technology networks, the role and influence of these actors within and between networks is considered here. Actors identified as having a significant role in both the MMT policy network and the automotive exhaust emissions control SIS include the auto industry and the refining industry.

Influence within the Networks

Although the Canadian Manganese-based Fuel Additives Act of 1997 was subsequently overturned due to conflicts with trade agreements, the initial passage of the MMT law, and thus success of auto sector interests over those of refiners, reflected, in part, the auto sector's greater relative economic strength and position in the Canadian economy at the time relative to Canadian refiners as well as its stronger policy capability which included better access to government departments of significance in this policy network. The economic recession of the early 1990s affected refiners to a greater degree than automakers which may have contributed to a relative lack of R&D in one sector (refiners) versus the other (auto) and thus indicated with which actor technological influence may have been held in the push for auto exhaust emissions reductions.

The auto industry's North American integration tied the Canadian auto industry more strongly into international coalitions than the Canadian refiners and allowed it to draw on the international backing of, not only the U.S. auto industry, but also formal automotive sector institutions that supported the harmonization of the industry world-wide including auto emissions control systems, standards, and vehicle fuels. This perhaps translated into less political leverage for the Canadian refiners relative to Canadian automakers in the MMT policy process.

The Canadian auto industry's integration with that of the U.S. was also a notable contrast to the domestic focus of the Canadian petroleum refining sector. The international trade benefit to Canada of the auto industry during the time period of interest was perhaps one of the most significant distinguishing factors between these two industry heavyweights in the politics of MMT policy process. Furthermore, the NAFTA and the AIT both undermined the MMT bill which would have ultimately required alternative means (including technology changes) to achieve octane in gasoline. These agreements helped the Canadian refining industry resist pressures for such technological change (diffusion). These pressures added to a legacy from the 1980s of weakened incentive for technical change wrought, in part, by government-set price differentials between heavy and light crude which reduced the attractiveness of upgrading equipment sooner rather than later to process the cheaper, heavy crude oil.

Within the exhaust emissions control technological network, as for the MMT policy network, Canadian automakers again appeared to hold relatively more influence than refiners. Automakers, although not conducting much exhaust emissions control R&D in Canada, were better connected internationally (from which they drew needed support including R&D from U.S. parent companies) and better supported institutionally (including a legacy of policy decisions that supported harmonization of standards with the U.S. and thus its technologies). Control of the process of technological change within this area tended toward the auto industry in the 1990s, especially with increasing focus on fuel formulations as a source of auto emissions reduction and view of motor vehicles and fuels as an integrated system. Such control meant that oil refiners' products would generally have to accommodate automaker technological changes for auto emissions reduction. Reduced attention to automotive fuel R&D by the Canadian refining sector was likely due to economic weakness in the 1990s, government policy (to set price differentials between heavy and light crude at a smaller margin than the market), and other technological interests (synthetic crude oil refining). Lags and apparent resistance to technology change related to automotive gasoline contributed to refiner difficulties in attempting to influence this SIS; the sector was positioned to be an "R&D/technology change-taker" from U.S. refiners, U.S. and Canadian automakers. Furthermore, general refiner interests in process over product technological change affected its ability to influence control over auto emissions exhaust technological change.

Implications for Influence between the Networks

As part of this exploration of auto and refining sector actor characteristics and policy and technology network influence, a consideration of whether technology may in fact be influencing policy in this case must be undertaken. It would seem that in seeking technology change for further auto tailpipe emissions control in the 1990s, both the auto and refining sectors have generally resisted moves towards radical technological change, instead opting primarily for diffusion of available technologies and, secondarily, incremental refinements to proven technologies with less attention to more radical technological changes. This situation may imply that technology is influencing policy rather than reverse given that diffusion of technology as the intent of policy is not a requirement for further development or innovation of technology but rather for widespread use. In the case of the refining sector, technological innovation for both RFG production and for octane enhancement without the use of MMT occurred in advance of policy change that essentially reflected the character and direction of change indicated by the innovation. For the auto sector, enhancements of the existing catalytic converter and development of the next generation of OBD technologies were perhaps relatively larger, though still incremental, changes to existing technologies. A further indication of the direction of influence in the relationship between technology and policy could be that environmental policy decisions and regulations are not based primarily on outcomes of debates about environmental impact and degree and rate of mitigation, but based rather on the outcomes of technological competition and cooperation within industry, ultimately favouring the interests of those who are also effective policy actors.

When considering factors related to actor characteristics that have advanced or hindered automotive exhaust emissions control technological change, it appears that only in a relatively limited way have the auto and refining sectors undertaken initiatives to work in concert. In the on-going drive to further reduce automotive exhaust emissions, these two sectors have sought to impose the burden of technology change upon each other. Given this context of tension between the auto and refining sectors, the influence of technology on policy-making in this case can be seen to be a function of the ability of each actor to command relatively greater influence in both types of networks. In this way, each actor must be examined in relation to the other to determine, not only whether technology influences policy, but whose technology influences policy (if the technology is systemic with significant links between two or more industries and if there is inter-sectoral conflict) and in what way (e.g., diffusion, incremental change, or radical change).

The balance between cooperation and competition amongst actors common to technology and policy networks affects the influence of technology on policy. Within the

MMT policy network, the auto and refining sectors were intensely competitive (with diametrically opposed interests) as policy actors. Within the technology network, although some cooperation existed (e.g., the AQIRP), the automakers and refiners were also directly competing with their technologies over the issue of near-term further reduction of automotive exhaust emissions and, less directly, for the future burden (precedent) of technological change in this policy area. Given that the auto industry was relatively more influential in the MMT policy network and again in the SIS, the expectation would be that the auto industry technological interests would be reflected in the policy outcome, thus, technology would be influencing policy. Although interest in this study is focused on understanding how technology may influence policy, a reciprocal relationship between technology and policy is acknowledged. In so doing, it is interesting to consider that in this case study automotive sector technology was working to influence policy to, in turn, change (diffuse) refiner technology.

V. Conclusions

This study has been a preliminary analysis of the interaction between policy and technology networks and has begun to reveal those actor characteristics which can serve to increase influence between such networks and, in this way, explored how technology can influence policy in this reciprocal relationship. As an initial review, further research is needed to better understand influences in the relationship between policy-making and technology change including the characteristics of the flows (e.g., knowledge, finance, and technology) and the nature of the links (e.g., quality, quantity, and asymmetry) between the MMT policy network and SIS. Further insight is also needed into the way in which institutional influences common to both types of networks can serve to connect policy and technology networks and shape the relationship between policy and technology. The significance in this case of the AIT and NAFTA for policy reversal against the interests of the auto industry, which appears to have predominated in both the policy network and the SIS, suggests that the importance of institutions should not be underestimated here.

This study tentatively suggests that if a private sector actor common to both policy and technology networks holds significant influence in both networks over other actors with which it is competing or in conflict, this actor's technological interests will influence policy-making in a given issue area. Based on this work, a few tentative conclusions are put forth: 1) The concentration, cohesion, control of innovation, position within a state's economy, and policy capability of an industrial sector affect the influence of technology on regulation; and 2) The balance between cooperation and competition amongst actors common to innovation and policy networks affects the influence of technology on regulation. Further work is needed to understand the implications for the technology-policy relationship in the case of an inter-industry conflict in which one industry actor is influential in one type of network while a second industry actor is influential in the other where both are active in both networks. Exploration of the dynamics of collaboration, competition, and coalition-building between sectors in the case of three or more industry actors common to a policy and technology network would provide further insight into the technology-policy relationship as well. In addition, the characteristics and role of the state within this relationship requires further examination.

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