Technological choices and regulation: the case of the Canadian manufacturing sectors

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Abstract. The economic environment in which Canadian manufacturing firms operate has changed substantially over the last 40 years. Technological changes, new regulations, deregulation, and exogenous economic shocks all have been important aspects of this economic environment. In this article, we show how to include such changes in the economic environment faced by the firms in a behavioural model that includes the investment decision of the firm under uncertainty. Assumptions regarding the expectation formation process and technology are kept minimal. We estimate the effects of innovations such as the free trade agreement, the foreign investment review agency, and the federal environmental policy on the economic decisions of fifteen Canadian manufacturing sectors. JEL Classification: D24

Choix de technologies et réglementation: le cas des secteurs manufacturiers canadiens. Au cours des 40 dernières années, l'environnement économique des firmes manufacturières canadiennes s'est grandement transformé. Que ce soit à cause du changement technologique, de la réglementation, de vagues de déréglementation ou de chocs économiques exogènes, les firmes ont dû s'adapter en modifiant leur technologie. Dans cet article, nous montrons comment prendre en compte les changements de l'environnement économique des firmes dans le cadre d'un modèle décisionnel de la firme en incertitude avec investissement. Les hypothèses concernant la technologie et les anticipations sont aussi générales que possible. Nous estimons l'effet qu'ont eu l'accord de libre échange, l'agence de tamisage des investissements étrangers et la politique environnementale fédérale sur les choix de technologies des firmes de quinze secteurs manufacturiers canadiens.

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1. Introduction

Investment is a deciding factor for economic growth and helps to explain economic development. While investment has often been the direct target of economic policy, many regulatory aspects of the economic environment have indirect effect on the firm's behaviour. The direct and indirect impacts of economic regulation are not well known, however, and have not been measured. Consequently, there is an interest in constructing and estimating a model to explain both the firm's investment decisions and its reaction to economic regulations. The Canadian governement has enacted a number of laws to regulate the behaviour and the economic environment of firms, which have a potential impact on investment decisions. In this paper, we use a model that allows us to include regulation in the investment decisions of the firm to evaluate how environmental regulation and international trade policy, especially towards foreign investment, have affected the investment decisions of Canadian manufacturing firms.

Over the last four decades, Canadian manufacturing firms have faced various changes in their economic environment. Some of the most important changes have taken place in the context of environmental regulation and international trade policies. The federal Department of Environment was created in the early 1970s, and the adoption of the Clean Air Act in 1971 soon followed. Many provinces have also developed further environmental regulations. These new regulations were enacted to enforce appropriate environmental behaviour on the part of firms. During the same period, the federal government moved from a restrictive international policy, creating the Foreign Investment Review Agency (FIRA) in 1974, to a liberalization of international trade in later years. In the time-frame of our study, the Free Trade Agreement (FTA) with the United States presents the best example of such a liberalization.

As we find in this article, these policies and regulations have affected the activities of manufacturing firms by providing new incentives to adopt technologies compatible with new environmental regulation and to adapt to new levels of competition with firms in the United States. Although these policies have not often targeted investment explicitly, they have undoubtedly had an impact. For example, the combination of the various acts on air and water pollution and regulated standards on the disposal of toxic wastes have contributed to affect the investment decisions and the industrial structure. In order to meet certain Canadian regulatory standards firms have had many options to achieve the required level of emission. Among the possibilities, the most common are lower production levels and modification to the technology. When a firm chooses to change its production process it must usually acquire either new non-polluting equipment or new components to add to the current production process to meet the standards. The firm may also halt the expansion of certain production lines if the process is too costly to adapt to the new standards. Thus, the consequence of such a policy may vary from one sector to another, so that investment is not bound to either increase or decrease. The results of our estimation of the technology of 15 Canadian manufacturing sectors tend to confirm this intuitive conclusion. Investment increased in seven sectors following the major changes in environmental regulation at the beginning of the 1970s, but decreased in the remaining eight. It also appears as though the firms' changes in investment were one-time responses rather than continuous and slow adaptations to the regulatory changes. In fact, most of the investment responses (either negative or positive) to changes in environmental regulation took place during the early 1970s.

It is interesting to note that Canada had two diametrically opposed views on foreign investment over the observed period. During the 1970s and the early 1980s foreign investment was perceived by some influencial groups as detrimental to Canada's development. This led to the creation of FIRA with the mandate to screen foreign investment applications in Canada and to accept only those providing significant benefits. With the election of the Tories in 1984 and the signing of the FTA, the attitude of Canadian institutions toward foreign investment shifted from suspicion to welcome. The governement was now encouraging and seeking new foreign investments. Although these two policies shared a common objective, at least partially, to increase real investment in Canada, the spirit of those policies is opposed. While FIRA sought domestic investors in the late 1970s, the federal government policy sought foreign investors after 1985. The verdict? Our results tend to show that while FIRA effect on investment was detrimental, the FTA's effect was somewhat positive. This confirms the conjecture that although the acceptance rate was high, the mere existence of FIRA itself was enough to deter profitable investment in the Canadian manufacturing sectors.

Investment plays a crucial role in the adaptation process of firms to changes such as regulation and economic environment as it allows the introduction of new technologies and the adaptation of old ones. However, the performance of traditional models of investment is somewhat limited in the context of those changes, partially owing to their inability to account for regulation. It hardly seems necessary to point out the importance of regulatory and environmental changes, but these factors do not often appear in the formal analysis of firm behaviour. We propose to include constraints imposed by the economic environment of the firm, such as the regulation mentioned above, in a dynamic optimization problem that can be used as the basis of an empirical model. By taking into account extra information not usually considered in investment models, we believe we can provide a new view of the empirical process of decision making by firms.

There is virtually no empirical dynamic analysis in the existing literature of firms' decisions that incorporates regulation. Usually, one assumes that a firm minimizes an expected discounted sum of costs. The model is made intertemporal by assuming that the stock of capital is quasi-fixed and obeys a dynamic law of movement. Demands are deduced from either a complete or an incomplete solution to the cost minimization problem. The form given to the solution (e.g., explicit solutions, information used, and so on) depends on the assumptions made regarding the expectation formation process and the technology. From an examination of these models, we conclude that a trade-off exists between the strength of the assumptions on the technology, the modelling of expectations, and the degree of completeness of the solution. One consequence of this trade-off is that the empirical specification implied by the different models is affected by the degree of specificity of the various assumptions. Typical examples of this literature include Berndt, Fuss, and Waverman (1979), Hansen and Sargent (1980, 1981), Kollintzas and Cassing (1985), Pindyck and Rotemberg (1983a,b), and Carmichael, Mohnen, and Vigeant (1990), among others.

Instead of directly solving the problem, a characterization of the solution in the price domain has been suggested in the hope of avoiding those trade-offs. McLaren and Cooper (1980) show that it is possible to relate the system of conditional factor demands to the value function of the given primal problem (the minimization of a discounted sum of costs). Under certain conditions, the technology is shown to be equivalent to its representation in the price domain (Epstein 1981). This early dynamic duality theorem relies heavily on assumptions of static expectations and of constant technology over time. Lasserre and Ouellette (1999) address this problem. They develop a form of dynamic duality that does not impose any particular structure on the expectation formation process and the technology of the firm. The solution to the problem yields a system of demands and investment functions, shown to be dual to the contemporary technology.

This literature on dynamic analysis does not take into account changes in the economic environment of the firm. It assumes that firms adjust exclusively to price changes. The problem of regulation and changes in environment has, however been addressed in the static case. In a seminal paper, Averch and Johnson (1962) introduce rate-of-return regulation into the firm's problem. The solution to the cost minimization problem has been characterized by Diewert (1981) and Fuss and Waverman (1981), while the duality between the cost function and the technology has been shown by Färe and Logan (1983). Lasserre and Ouellette (1994) characterize the cost function under generalized additional constraints, while Ouellette and Vigeant (2001a) characterize the technology in a general context.

Our approach in this paper combines a dynamic model à la Lasserre and Ouellette (1999) with the introduction of general additional constraints in the tradition of Averch and Johnson. The typical firm is assumed to be an intertemporal cost minimizer. The link between the periods is established via investment decisions. The expectation formation process is not required to have a particular form. Cost minimization is subject to technological, dynamic, and additional constraints. The latter determine how the model captures the environmental changes mentioned above. No a priori structure on the form of these restrictions is imposed, other than some standard regularity conditions.

A system of factor and investment demands is deduced. This system of demands has been shown to be a dual representation of the technology in Ouellette and Vigeant (2001b). This demand system is the tool used to measure technological progress and returns to scale and to provide some measures of flexibility in selected Canadian manufacturing sectors.

2. Characteristics of investment

Investment is central in terms of the technological choices facing the firm, as adjustment of capacity as well as new technologies are introduced via investment in new capital goods. Therefore, a correct characterization of investment behaviour is desirable. Unfortunately, the investment behaviour of the firms is not easy to identify. While most traditional inputs (labour, energy, and materials) follow a fairly stable pattern, investment tends to show complex patterns in many sectors. The investment variable seems to respond to a large set of incentives extending beyond the purchase price of capital goods.

Figure 1 shows the evolution of investment and its price for three Canadian Manufacturing Sectors (Food and Beverage Industries, Coal and Petroleum Industries, and Non-Metallic Minerals Products). The investment series has been divided by output in order to account for business cycle effects on investment. The price of investment is corrected for taxes and is deflated by the price of output.[1] Despite similar evolutions of the relative price of investment across sectors, the behaviour of investment differs substantially, ranging from a relatively continuous increase (Food and Beverage) to oscillations (Non-Metallic Minerals Products). In fact, the input prices cannot explain more than 8% of the variability of investment in the Non-Metallic Minerals Products, while in the Food and Beverage Industries, they were responsible for 88% of the variability.[2] In many sectors input prices and output alone cannot explain the variability of investment, leaving the door open to alternative explanations.

It should also be observed that the volatility of investment has changed considerably during the 1970s. In seven sectors it has substantially increased, while in four others it has decreased.[3] In virtually every sector there has been a decade in which the volatility of investment has increased by more than 50%.

1 The reader is referred to appendix A for a complete description of the database and investment summary statistics.

2 This result is obtained by regressing the logarithm of investment on input prices and the price of output. A more satisfactory exercise consists in estimating a simple 'conditional factor demand' for investment. That is, the logarithm of investment is regressed on the logarithm of the input prices (labour, materials, energy, and investment) and output. This accounts for some business cycle effect and it includes the prices upon which the firms' decisions are based. The results of such an experiment show virtually no improvement as prices do not exhibit strong explanatory power. The parameter corresponding to the price of investment is often of the wrong sign and/or not significant.

3 We have corrected our measure of the variance for possible changes in the mean of the investment series by using the coefficient of variation for the three decades considered.

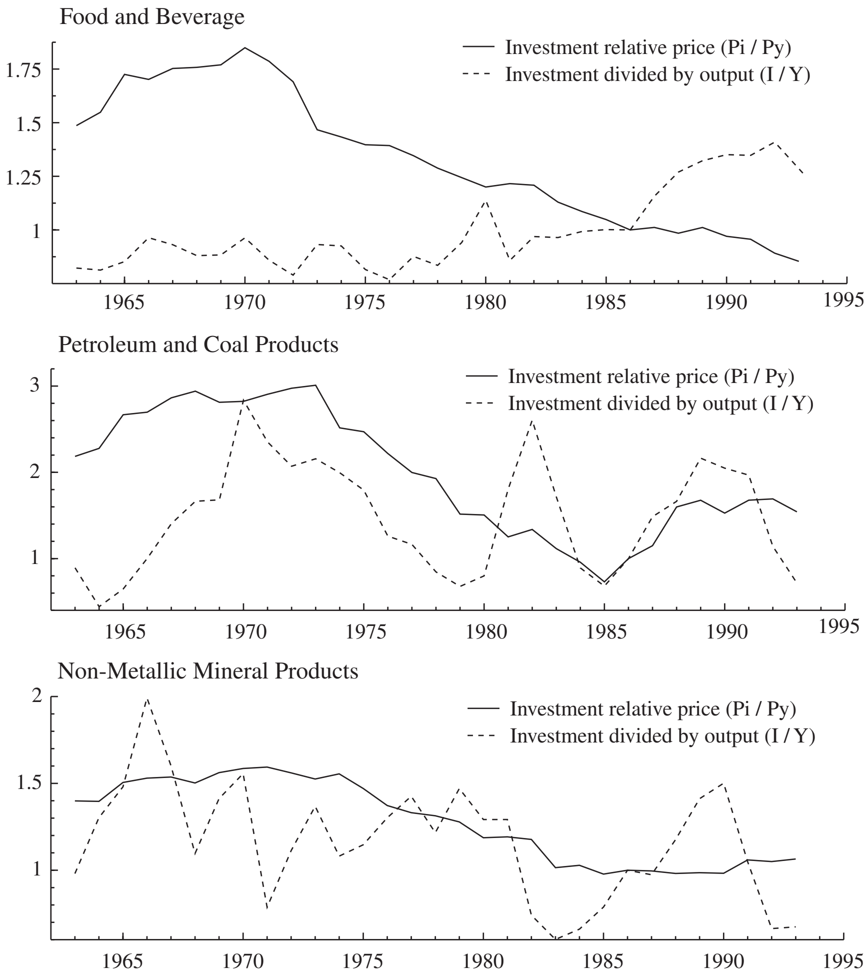

FIGURE 1 Investment and relative price

This is definitely not a stylized behaviour of the prices. This means that prices do not adjust quickly enough to provide all the information necessary to make the investment decision. Thus, the firm has to complement its investment decision with other sources of information. There are two possible channels available to complement the information included in the prices. The first consists of the set of regulations and changes in the economic environment faced by the firm. For example, announced changes in the trade agreement between Canada and the United States may trigger a number of alternative investment plans, while the price of investment goods only adjusts subsequently. Even though the changes to the firms' environments (in particular regulation changes) are the same for all industries, the reaction of each sector will be specific, since the circumstances and specific perceptions of the regulation will differ across sectors. Then, each sector will prepare a specific response to a common change in the environment. For example, the Free Trade Agreement establishes the same rules for the various manufacturing industries. Owing to the Auto Pact, the transportation equipment industry will interpret this change of environment differently than the textile industry, which had been heavily protected by tariffs. Consequently, even though the regulation does not vary across sectors, one might expect different reactions from each specific industry. Secondly, by the intrinsic intertemporal nature of investment decisions, firms have to form plans on the future. For this reason they have strong incentives to use all available information in order to make the best decision today. New investment requires that they lock into a given technology. Consequently, each industry has a specific relevant information set. For some sectors, past prices can be sufficient, while for others the past and present level of activity of the whole economy is relevant. Therefore, to capture more efficiently the economics behind the investment decisions of firms, regulation and information other than those included in prices should be relevant and must be included in a theoretically consistent empirical model.

Thus, it is possible that the observed price of investment goods does not entirely reflect the real cost of investing. Investment reflects the future decisions of a firm. The contemporary level of investment includes future expectations of the market conditions. Investment decisions may also result from incentives provided by institutional aspects not accounted for directly in the prices of capital goods. For these reasons, in a later section we will develop a model that can encompass various forms of regulation in a dynamic model of the firm. This model will then be applied to the Canadian manufacturing data, and we will evaluate how the environmental and international trade policies of Canada have affected the investment decisions of the firms.

3. The regulation

Canada has seen many changes in its regulatory environment over the last four decades. As shown in this article, changes in regulation have affected the technological choices of manufacturing sectors. To see how this is possible, one must first understand the major institutions and facts concerning the Canadian regulatory environment. This section presents a brief overview of the international and environmental regulations studied here.

3.1. The environmental regulation

Canadian environmental legislation is based on a model of cooperation between firms and the government to obtain negotiated contracts. Before the 1990s negotiation and moral suasion were used extensively to achieve compliance with the law. This has recently changed with the growing reliance on the legal system. Initially, the regulation was a set of guidelines on emission objectives and pollution targets, while specific standards were rarely specified. Incentive-based mechanisms to control emissions were not used, since the government relied mostly on command-and-control policies. Although a regulation was put in place, no obligation to act was imposed on the officials, thus adding to the difficulties to reach the objective and targets in the regulation.

Although all levels of government (federal, provincial, and municipal) have the right to enact environment regulations, it is the provinces that have the most power. This may help to explain why the Ontario Water Resources Commission was the first agency created (in 1956) with a specific environmental mandate. It is the federal government, however, that has taken most of the subsequent initiatives. The federal government used its jurisdiction over the ocean and inland fisheries, navigation and shipping, and federal lands and waters to enact laws aimed at pollution control. The power given by the British North America Act to enact legislation in the interest of 'peace, order and good government' was used to put forward the Canadian Environmental Protection Act and legislation on toxic wastes. The lack of separation of power over the environment has led to conflicting legislations that called for substantial court interventions.

Environment Canada (EC) was created in 1971. It brought under the same umbrella a number of federal agencies with environmental responsibilities. At the time, some efforts to control air and water pollution were made. Despite this promising beginning, the environment has never been an active priority until the late 1980s and the beginning of the 1990s. EC did not have a high-profile minister between 1971 and 1986 (10 different ministers and many reorganizations over that period were symptomatic of the minor role played by EC). Accentuating this minor role was the budgetary process. While EC was once funded under the social development envelope, the lion's share went to health and welfare. More important, EC was separated from the economic agencies, making the environment a social issue only. This contributed to the creation of policies with weak reliance on economic incentives. However, by the late 1980s the environmental policy hit an upswing. In 1988 the Canadian Environmental Protection Act was enacted, followed by the Canadian Assessment Act and a multitude of public administration changes attracting more attention to the environment. In 1990 the federal government published the 'Green Plan.' The plan proposed a new framework for environmental policy based in part on economic theory. Accordingly, the governement objectives were oriented into three major categories. First, the traditional role of curbing pollution by keeping clean air, water, and land; second, the sustainable exploitation of natural resources, which includes managing the renewable resources and protecting species and space (including the northern regions of Canada); and third, a policy aimed at the management of environmental hazards, which includes, in particular, the promotion of environmental security and the development of emergency plans.

3.2. The Foreign Investment Review Agency
In the early 1970s Canadians were concerned with the extent of foreign control and ownership over the industrial sectors. These concerns were addressed by the Gray report published in 1972, which led the government to create an agency to screen foreign acquisitions of domestic firms. The agency's objective was to accept only those mergers that would provide a significant benefit to Canadians. This is essentially how the Foreign Investment Review Agency (FIRA) was born in 1973.

The objective of FIRA was clearly to increase domestic ownership of the industrial sector. It was expected that given the opportunity to invest, Canadians would increase the presence of domestically owned industries. FIRA reviewed all acquisitions exceeding $250,000 in assets, as well as new foreign investment proposals. Of the 5230 applications reviewed between 1974 and 1983, 4185 were accepted, 398 were rejected, and the remaining applications were withdrawn before the final decision was made. (The percentage of accepted and withdrawn applications varied substantially over the period in response to changes of the minister responsible for the agency.)

However, the number of rejected proposal can only partially explain FIRA's influence. In fact, it was the minister in charge of the agency who had a substantial impact on the number of applications withdrawn or delayed. During the hostile period between 1980 and 1981, when Herb Gray was in charge of the agency, the number of withdrawn and delayed cases increased. This eventually led to his replacement, which coincided with an increase in the number of applications and the resolution of hanging cases. One of the probable effects of FIRA was a decline in foreign control at the turn of the 1980s. It is also possible that because of the existence of the screening process, many projects were simply not undertaken, despite the fact that the acceptance rate was quite high.

With the election of the Progressive Conservative government in 1984, the role of FIRA as a screening agency declined. In 1985 the government renamed the agency Investment Canada and changed its mission to attract foreign investment into Canada. This made the agency appear much less intimidating, as only culturally sensitive areas were now subject to review (although it was officially reviewing takeovers worth $5 million or more).

3.3. The Free Trade Agreement
The Canada-U.S. Free Trade Agreement (FTA) was signed on 2 January 1988 and came into effect on 1 January 1989, following legislation in both Canada and the United States. The agreement introduced a greater freedom in trade, although it was not comprehensive and eliminated only certain types of protections.

The FTA is not a simple matter, the document being 300 pages long and including hundreds more pages in appendix. The most important provision however, is that tariffs between Canada and the United States were to be reduced and eventually eliminated, in one, five and ten years from 1 January 1988. The FTA also specifies that non-tariff barriers to trade are to be eliminated either at the beginning of the agreement, or according to a given timetable. It aims especially at non-agricultural trade quotas. The FTA also turns its back on the type of policy that FIRA represented by increasing the freedom to invest in the other countries. For Canada, this meant that the threshold for review was to be gradually increased to $150 million between 1989 and 1993 and allowing Canadians investing in the United States to obtain the same treatment as Americans. The FTA also created a continental energy policy. While it frees energy from tariffs, quotas, subsidies, and export taxes, as one should expect from a trade agreement, it also included a 'non-discriminatory access' clause. This means that Canada can no longer apply dual price policies, as was done under the National Energy Policy during the late 1970s and early 1980s. In case of energy shortages, the FTA also prohibits reductions of exports of energy by a higher percentage than the production reductions of energy destined for domestic consumption.

The FTA includes services, such as insurance, financial, computer-related, equipment rental and leasing, and management. Although professional services are included, they exclude health, education and social services. This reflects the growing importance of services in national and international economic activity and how services are now an entire part of the production and distribution of goods. At the time, such treatment of services was unique to the FTA.

An agreement such as the FTA is certainly not free from dispute or diverging interpretation of its content. For this reason, a binational panel was established to handle disputes arising over the interpretation and operation of the FTA. The primary role of the panel would be to determine if exported goods have benefited from subsidies or if lower domestic prices indicate dumping. Since many provisions have not been defined in the agreement and have been left for further negotiation, the effectiveness of the panel may have been compromised. For example, what constitutes a subsidy is not defined and does not prevent the United States from interpreting low stumpage fees as subsidies and installing countervailing duties. In such a case, the panel would be called upon for an interpretation. Nevertheless, the agreement stipulates that an appeal is only a last resort, when either country has already decided alone that countervailing measures should be undertaken.

4. The model

In this section we present a model that incorporates changes in the firm's economic environment in a dynamic setting. The major difficulty is to include regulation in the optimization problem in a general form so that it will not impose a structure that may bias the result a priori. In some cases these additional constraints are easily represented; one may think of floor or ceiling prices, quotas, value constraints, and so on. The rate-of-return à la Averch and Johnson (1962) is the best known of these simple constraints. The regulations studied in this paper, however, are not as easily represented. Environmental regulation is fairly complex and is expressed in a multitude of laws. The present period of free trade with the United States was preceded by one of restrictions, FIRA being the foremost example of state control over international business. These types of regulation are difficult to represent by an explicit set of equations, although it is difficult not to acknowledge their impact. Therefore, we need a model that includes the changes in the economic environment of the firm and, at the same time, provides a consistent representation of the technology.

It is assumed that the firm solves an intertemporal cost-minimization problem. To account for the regulation, this problem is supplemented by the addition of a set of vector-valued functions, **h**. These functions are treated in exactly the same manner as the production function: they are implicit functions defining restrictions on the input requirement set. In other words, we do not have to explicitly specify the functional forms of the additional constraints. Like the production function, a set of additional constraints is included in the firms's optimization problem as a vector of implicit functions, where these additional constraints are assumed to satisfy a number of regularity conditions.

The additional constraints appear under the form of an r-vector of implicit functions written as

$$\mathbf{h}(y_t, \mathbf{x}_t, \mathbf{i}_t, \mathbf{k}_t, \mathbf{J}_t, \boldsymbol{\phi}_t) \leq 0, \tag{1}$$

where $\boldsymbol{\phi}$ is the vector of regulation variables and $\mathbf{J}$ is the vector of variables in the firm's information set. Thus, the general problem of the firm is[4]

$$G(\mathbf{J}_t, \mathbf{k}_t, y_t, t, \boldsymbol{\phi}_t) = \min_{\{\mathbf{x}_\tau(\cdot),\, \mathbf{i}_\tau(\cdot)\}} E_t \left\{ \sum_{\tau=1}^{T} \left[\frac{\rho_\tau}{\rho_t} (\mathbf{w}_\tau^T \mathbf{x}_\tau + \mathbf{q}_\tau^T \mathbf{i}_\tau) \right] \right\} \tag{2}$$

such that

$$\begin{aligned}
& y_\tau \leq f(\mathbf{x}_\tau, \mathbf{k}_\tau, \mathbf{i}_\tau, \tau) && \tau = t, \ldots, T \\
& \mathbf{k}_{\tau+1} = \mathbf{k}_\tau(\mathbf{I} - \boldsymbol{\delta}_\tau) + \mathbf{i}_\tau && \tau = t, \ldots, T \\
& \mathbf{h}(y_\tau, \mathbf{x}_\tau, \mathbf{i}_\tau, \mathbf{k}_\tau, \mathbf{J}_\tau, \boldsymbol{\phi}_\tau) \leq \mathbf{0} && \tau = t, \ldots, T \\
& \mathbf{k}_t \text{ and } y_t \text{ given,}
\end{aligned}$$

where $\mathbf{x}_t$ and $\mathbf{w}_t$ denote, respectively, the vectors of variable inputs and prices; $\mathbf{i}_t$ and $\mathbf{q}_t$ are the vectors of investment and investment prices, respectively; **t** is a time trend capturing technological progress, ρ_t is a discounting factor, defined

4 The time horizon, T, does not have to be finite. It does not affect the characterization of the solution of this optimization problem.

as $\rho_\tau = (\prod_{s=t}^{\tau} 1/(1+r_s))$, r_s is the discounting rate, and E_t is the conditional expectation operator based on all relevant information. The information set, $\mathbf{J}_t$, is defined as

$$\mathbf{J}_t = [\mathbf{w}_t, \mathbf{q}_t, \xi_t, \boldsymbol{\sigma}_t], \tag{3}$$

where

$$\xi_t = \frac{\rho_{t+1}}{\rho_t} \tag{4}$$

and

$$\boldsymbol{\sigma}_t = \left(\left\{\mathbf{w}_\tau, \mathbf{q}_\tau, \xi_\tau, \boldsymbol{\theta}_\tau, \tau, \boldsymbol{\phi}_\tau\right\}_{t-S}^{t-1}, \boldsymbol{\theta}_t\right), \tag{5}$$

where S is finite and $\boldsymbol{\theta}$ is a set of relevant variables, including business cycle variables such as GDP and the unemployment rate.

To characterize the solution of this problem, we need to specify what constitute the admissible production functions and additional constraints.

ASSUMPTION 1. *The production function* $f(\mathbf{x}, \mathbf{i}, \mathbf{k}, t)$ *satisfies the following regularity conditions:*

(i) f is twice continuously differentiable, $f \in \mathcal{C}^2$;
(ii) f is increasing in $\mathbf{x}$ and $\mathbf{k}$, $f_x > 0$ and $f_k > 0$;
(iii) f is strongly quasi-concave in $\mathbf{x}$ and $\mathbf{i}$. That is, its Hessian is negative definite,

$$\boldsymbol{\mu}^T \begin{bmatrix} f_{xx} & f_{xi} \\ f_{ix} & f_{ii} \end{bmatrix} \boldsymbol{\mu} < 0,$$

in all directions $\boldsymbol{\mu} \neq 0$ such that $[\, f_x \quad f_i \,]\, \boldsymbol{\mu} = 0$.

The first two conditions are standard. Strong quasi-concavity ensures differentiability of the solution everywhere. There is no restriction on f_i, so that adjustment costs ($f_i < 0$) are possible, but not necessary. The existence of adjustment costs is therefore an empirical question.

To ensure that the problem is not vacuous or solely determined by the constraints, it is required from the vector of additional constraints that the rank of the first derivatives of $\mathbf{h}$ with respect to $(\mathbf{x}, \mathbf{i})$ be strictly less than $m+n$, where n is the dimension of $\mathbf{x}$, and m is the dimension of $\mathbf{i}$. The following assumption defines admissible additional constraints.[5]

5 Ouellette and Vigeant (2001a,b) discuss and present various specific functional forms that the vector function **h** can assume and that are consistent with assumption 2. Imposing such specific forms allows us to obtain a richer characterization of the technology. However, when **h** is of unknown functional form but satisfies the minimal restrictions required by assumption 2, the technology can still be identified.

ASSUMPTION 2. *The additional constraints,* $\mathbf{h}(y, \mathbf{x}, \mathbf{i}, \mathbf{k}, \mathbf{J}, \boldsymbol{\phi})$ *satisfy the following regularity conditions:*[6]

(i) $\mathbf{h}$ *is twice continuously differentiable,* $\mathbf{h} \in \mathcal{C}^2$*;*

(ii) the Jacobian matrix $[\mathbf{h}^j_{X_i}(y_t, \mathbf{x}_t, \mathbf{i}_t, \mathbf{k}_t, \mathbf{J}_t, \boldsymbol{\phi}_t)]_{ji}$ *is not perfectly collinear with the vector of implicit prices* $[\mathbf{w} \quad \mathbf{q} + \overline{C}_{k_1}]$*;*

(iii) $\mathbf{h}$ *is quasi-convex in* $\mathbf{x}$ *and* $\mathbf{i}$*. This implies that, for all directions* $\boldsymbol{\omega} \neq 0$ *such that* $[\mathbf{h}^j_x \quad \mathbf{h}^j_i]\boldsymbol{\omega} = 0$*, the Hessian is positive semi-definite,*

$$\boldsymbol{\omega}^T \begin{bmatrix} \mathbf{h}^j_{xx} & \mathbf{h}^j_{xi} \\ \mathbf{h}^j_{ix} & \mathbf{h}^j_{ii} \end{bmatrix} \boldsymbol{\omega} \geq 0,$$

$j = 1, \ldots, r;$

(iv) There exists a bounded sequence of additional constraint parameters, $\{\bar{\boldsymbol{\phi}}_s\}_{s=0}^t$*, such that, given* y_t *and* $\mathbf{k}_t$*, the input requirement set associated with the additional constraints satisfies the following condition:*

$$E_t\{(\mathbf{x}_\tau, \mathbf{i}_\tau) \mid \mathbf{h}(y_\tau, \mathbf{x}_\tau, \mathbf{i}_\tau, \mathbf{k}_\tau, \mathbf{J}_\tau, \boldsymbol{\phi}_\tau) \leq 0, \mathbf{k}_{\tau+1} = \mathbf{k}_\tau(\mathbf{I} - \boldsymbol{\delta}_\tau) + \mathbf{i}_\tau\} = \mathbb{R}^{n+m}$$

for all $\mathbf{J}_t$*, and all* $\tau = t, \ldots, T$*.*

Assumption 2 (*i*) is purely technical, while assumption 2 (*ii*) ensures that the uniqueness of the solution to problem (2) will not be threatened by a misbehaved $\mathbf{h}(\cdot)$. Assumption 2 (*iii*) is sufficient for the second-order conditions to be satisfied. Finally, assumption 2 (*iv*) states that the admissible additional constraints are *removable*. For this to hold, a sequence of past and present regulation parameters, $\{\bar{\boldsymbol{\phi}}_s\}_{s=0}^t$, such that the future additional constraints are perceived by the firm as non-binding must exist. This assumption is necessary for the duality result to hold, as shown by Ouellette and Vigeant (2001b).

Problem (2) has a recursive structure and can be rewritten using standard dynamic programming arguments. Since all future decisions are based on current choices, they can be embodied in a separate problem that can be solved conditionally on the current period decisions. The solution of this new problem is the expected future cost function, defined as

$$\overline{C}(\mathbf{J}_t, \mathbf{k}_{t+1}, t, \boldsymbol{\phi}_t) = E_t\left\{ \min_{\{\mathbf{x}_\tau(\cdot),\, \mathbf{i}_\tau(\cdot)\}} \sum_{\tau=t+1}^{T} \left[\frac{\rho_\tau}{\rho_{t+1}} (\mathbf{w}_\tau^T \mathbf{x}_\tau + \mathbf{q}_\tau^T \mathbf{i}_\tau) \right] \right\} \tag{6}$$

such that

$$\begin{aligned} &y_\tau \leq f(\mathbf{x}_\tau, \mathbf{k}_\tau, \mathbf{i}_\tau, \tau) && \tau = t+1, \ldots, T \\ &\mathbf{k}_{\tau+1} = \mathbf{k}_\tau(\mathbf{I} - \boldsymbol{\delta}_\tau) + \mathbf{i}_\tau && \tau = t+1, \ldots, T \\ &\mathbf{h}(y_\tau, \mathbf{x}_\tau, \mathbf{i}_\tau, \mathbf{k}_\tau, \mathbf{J}_\tau, \boldsymbol{\phi}_\tau) \leq 0 && \tau = t+1, \ldots, T. \end{aligned}$$

6 $\mathbf{h}^j_x$ is the line-vector of the partial derivatives of the *j*th regulatory constraint with respect to the vector $\mathbf{x}$, and $\mathbf{h}^j_{xx}$ is the matrix of second partial derivatives..

Because all information relevant for future decisions is included in $\overline{C}$, the assumption characterizing expectations can be restated in terms of restrictions on the expected future cost function. The following assumption restricts the class of solutions to unique solutions. Formally:

ASSUMPTION 3. *Given well-behaved f and* $\mathbf{h}$,[7] *there exist expectations such that the solution to problem 2 is unique. Furthermore, the solution is consistent with the existence of a unique expected future cost function,* $\overline{C}(\mathbf{J}_t, \mathbf{k}_{t+1}, t, \boldsymbol{\phi}_t)$, *of class* C^2. *The partial derivatives of* $\overline{C}(\cdot)$ *with respect to* $\mathbf{k}_1$ *satisfy* $\overline{C}_{k_1} < 0$, *and the matrix of second derivatives with respect to* $\mathbf{k}_1$, $\overline{C}_{k_1k_1}$, *is positive semi-definite.*

This assumption complies with the conditions frequently imposed in applied models. For instance, when expectations are static and assumptions 1 and 2 hold, the solution to problem (2) is compatible with assumption 3. In particular, this encompasses the model described by Epstein (1981). Assumption 3 is also compatible with the adaptative expectations model of Epstein and Denny (1983). If we further assume that the functions $\mathbf{h}$ and f are quadratic and the prices are generated as Box-Jenkins time series processes, the problem under assumption 3 complies with the conditions of rational expectations model of the Hansen and Sargent (1980, 1981). This formulation of the problem is also compatible with a version of Cooper, Madan, and McLaren (1989), where the prices follow Wiener processes and first-period variables are observed. When assumption 3 holds, problem (2) can be rewritten as follows:

$$G(\mathbf{J}_t, \mathbf{k}_t, y_t, t, \boldsymbol{\phi}_t) = \min_{\mathbf{x}_t(\cdot), \mathbf{i}_t(\cdot)} \left\{ \mathbf{w}_t^T \mathbf{x}_t + \mathbf{q}_t^T \mathbf{i}_t + \overline{C}(\mathbf{J}_t, \mathbf{k}_{t+1}, t, \boldsymbol{\phi}_t) \right\} \tag{7}$$

such that

$$y_t \leq f(\mathbf{x}_t, \mathbf{k}_t, \mathbf{i}_t, t)$$
$$\mathbf{k}_{t+1} = \mathbf{k}_t(\mathbf{I} - \boldsymbol{\delta}_t) + \mathbf{i}_t$$
$$\mathbf{h}(y_t, \mathbf{x}_t, \mathbf{i}_t, \mathbf{k}_t, \mathbf{J}_t, \boldsymbol{\phi}_t) \leq 0$$

$\mathbf{k}_t$ and y_t given.

The expected future cost function is unique and differentiable, by assumption 3, and the set of expectations satisfying this assumption is not empty (in particular, rational and static expectations satisfy it). Given the existence of an interior solution, assumptions 1, 2, and 3 are sufficient to ensure that the conditions of the Implicit Function Theorem hold. Therefore, there exist conditional factor demand functions, $\mathbf{x}(y_t, \mathbf{k}_t, \mathbf{J}_t, \boldsymbol{\phi}_t, t)$, and investment functions, $\mathbf{i}(y_t, \mathbf{k}_t, \mathbf{J}_t, \boldsymbol{\phi}_t, t)$, solving problem (7). It is shown by Ouellette and Vigeant (2001b) that such a demand system is a dual representation of the technology.

The principal characteristic of our model is its ability to deal with regulation of unknown form in a manner consistent with theory. As such, we can

7 For example, functions satisfying assumptions 1 and 2.

introduce regulation variables into empirical models, such that the estimated model is still consistent with the optimizing behaviour of the firm. Consequently, the model can handle regulatory restrictions and changes in the firm's environment (represented by the vector-valued function $\mathbf{h}(y, \mathbf{x}, \mathbf{i}, \mathbf{k}, \mathbf{J}, \boldsymbol{\phi})$) without the need to specify the exact functional form of the additional constraints (a fortiori of regulatory restrictions and changes in the firm's environment). We only require standard regulatory conditions (assumption 2) very similar to those generally assumed for a production function. From an empirical point of view, the least constraining way in which to include regulation in a model is to make use of variables representing the regulation without specifying the exact relationship linking the variables. When the exact functional form is known, it should be introduced into the problem to provide a richer characterization of the solution (i.e., the conditional factor demands). In fact, there is a trade-off between the characterization of the demand and the specificity of the functional form of the regulation. However, if the functional form is not exactly known and is mispecified, it may lead to a biased estimation of the technology.

For example, environmental regulation is extremely complex and cannot be synthesized into a simple functional form such as the fair rate-of-return of Averch and Johnson (1962). Following the argument outlined above, instead of a specific functional form for the regulatory constraints, the empirical strategy would be to specify a set of regulatory variables that can capture the strength of the regulation and estimate a demand system including them. The minimal characterization of the system of demand compatible with the technology is given in Ouellette and Vigeant (2001b).

Under its weakest form (no functional form for the regulation) the demands implied by our model differ from the standard demands (with no regulation) only by the regulation variables. It is possible to consistently account for complex regulation by including regulation variables in the empirical specification of the demands, as long as $\mathbf{h}$ satisfies assumption 2. In other words, the relationship between the regulation and the factor demand does not have to be made more precise than the relationship between the fixed stock of capital and the production technology in standard applied production analysis. In any case, under assumption 2, the characterization of the demand functions is consistent with the technology.

5. Estimation and data

The theoretical model of the previous section provides the basis for the recovery of the technology of a firm from the factor demands . In this section, we will apply this model to a sample of 15 Canadian Manufacturing Sectors, for the period 1962–93. The data allow us to estimate the factor demands for labour, materials, and energy, as well as the investment schedule. The data set is described in appendix A.

The choice of functional forms to approximate conditional factor demands is bound up with the question of flexibility in the sense of Diewert and Wales

(1987, 1988). The literature on conditional factor demands in a static framework implies that a cost function in order to be flexible must be at least a second-order Taylor expansion (Barnett 1983). In turn, application of Shephard's Lemma implies that the conditional factor demands are first-order Taylor expansions. Consequently, a second-order Taylor expansion of a conditional factor demand would be more than flexible in the static case. In the dynamic case it has not been possible to reproduce such results to characterize the flexibility of the factor demands. However, we know that a second-order Taylor expansion ensures that the marginal products depend on the arguments affecting the demands. Although it is not possible to prove the flexibility of a quadratic system of factor demands used as an approximation to the true factor demands in a dynamic framework, such a demand system possesses the minimal required characteristics to estimate the technology of a firm. The use of an approximation to the true conditional factor demands raises the problem identified by White (1979). Despite the fact that the approximation problem is formally true, Gagné and Ouellette (1998) have shown that it can be overlooked when the data are of a sufficient quality.

Since a quadratic approximation to the conditional factor demands has satisfying properties for our purpose, it is the functional form that we use to estimate the factor demands and investment function. The individual factor demands are defined as follows:

$$
\begin{aligned}
x^l = {} & \alpha^l + \sum_i \alpha_i^l w_i + \alpha_q^l q + \sum_a \alpha_a^l J_a^{(-)} + \sum_r \alpha_r^l \phi_r + \alpha_k^l k + \alpha_y^l y + \alpha_\tau^l t \\
& + \frac{1}{2} \sum_i \sum_{i'} \beta_{ii'}^l w_i w_{i'} + \sum_i \beta_{iq}^l w_i q + \sum_i \sum_a \beta_{ia}^l w_i J_a^{(-)} \\
& + \sum_i \sum_r \beta_{ir}^l w_i \phi_r + \sum_i \beta_{ik}^l w_i k + \sum_i \beta_{iy}^l w_i y \\
& + \sum_i \beta_{i\tau}^l w_i t + \frac{1}{2} \beta_{qq}^l q^2 + \sum_a \beta_{qa}^l q J_a^{(-)} + \sum_r \beta_{qr}^l q \phi_r + \beta_{qk}^l qk + \beta_{qy}^l qy + \beta_{q\tau}^l qt \\
& + \frac{1}{2} \sum_a \sum_{a'} \beta_{aa'}^l J_a^{(-)} J_{a'}^{(-)} + \sum_a \sum_r \beta_{ar}^l J_a^{(-)} \phi_r + \sum_a \beta_{ak}^l J_a^{(-)} k + \sum_a \beta_{ay}^l J_a^{(-)} y \\
& + \sum_a \beta_{a\tau}^l J_a^{(-)} t + \frac{1}{2} \sum_r \sum_r \beta_{rr}^l \phi_r \phi_r + \sum_r \beta_{rk}^l \phi_r k + \sum_r \beta_{ry}^l \phi_r y \\
& + \sum_r \beta_{r\tau}^l \phi_r t + \frac{1}{2} \beta_{kk}^l k^2 + \beta_{ky}^l ky + \beta_{k\tau}^l kt + \frac{1}{2} \beta_{yy}^l y^2 + \beta_{y\tau}^l yt + \frac{1}{2} \beta_{\tau\tau}^l t^2,
\end{aligned}
\tag{8}
$$

and the investment function is

$$
\begin{aligned}
I = {} & \nu + \sum_i \nu_i w_i + \nu_q q + \sum_a \nu_a J_a^{(-)} + \sum_r \nu_r \phi_r + \nu_k k + \nu_y y + \nu_\tau t \\
& + \frac{1}{2} \sum_i \sum_{i'} \eta_{ii'} w_i w_{i'} + \sum_i \eta_{iq} w_i q + \sum_i \sum_a \eta_{ia} w_i J_a^{(-)} + \sum_i \sum_r \eta_{ir} w_i \phi_r \\
& + \sum_i \eta_{ik} w_i k + \sum_i \eta_{iy} w_i y + \sum_i \eta_{i\tau} w_i t + \frac{1}{2} \eta_{qq} q^2 \\
& + \sum_a \eta_{qa} q J_a^{(-)} + \sum_r \eta_{qr} q \phi_r + \eta_{qk} qk + \eta_{qy} qy + \eta_{q\tau} qt \\
& + \frac{1}{2} \sum_a \sum_{a'} \eta_{aa'} J_a^{(-)} J_{a'}^{(-)} + \sum_a \sum_r \eta_{ar} J_a^{(-)} \phi_r + \sum_a \eta_{ak} J_a^{(-)} k + \sum_a \eta_{ay} J_a^{(-)} y \\
& + \sum_a \eta_{a\tau} J_a^{(-)} t + \frac{1}{2} \sum_r \sum_r \eta_{rr} \phi_r \phi_r + \sum_r \eta_{rk} \phi_r k + \sum_r \eta_{ry} \phi_r y \\
& + \sum_r \eta_{r\tau} \phi_r t + \frac{1}{2} \eta_{kk} k^2 + \eta_{ky} ky + \eta_{k\tau} kt + \frac{1}{2} \eta_{yy} y^2 + \eta_{y\tau} yt + \frac{1}{2} \eta_{\tau\tau} t^2, \qquad (9)
\end{aligned}
$$

where both the subscript i and the superscript l denote the summation index for labour, materials and energy; w_j is the price of the variable factor j; I and q denote investment and the effective purchasing price of capital;[8] $\mathbf{J}$ is the information set of which $\mathbf{J}^{(-)}$ is a subset excluding the current factor prices, w_{jt} ($j = 1, 2, 3$) and q_t;[9] ϕ is the vector of the additional constraints variables; k, and y denote the stock of capital and the level of output; and t is a time index used to capture technological progress.

Two problems arise with the functional form above. First, the number of sample points is fairly limited in comparison to the number of parameters. Consequently, we cannot estimate each parameter and we must set to zero a number of second-order terms, β_{ij}^k and η_{ij}, a priori. However, a sufficient number of the second-order terms remain, ensuring that the marginal products depend on the argument of the demand functions, so that essential aspects of the flexibility of the functional form are kept. Second, estimation of the functional form without imposing restrictions on the parameters complicates the identification of the technology. There is, however, an easy way out of this problem. The methodology for recovering the marginal products requires that

8 A great advantage of our model is that it does not require the computation of any Jorgenson-type rental price for capital. It is well-known that the behavior of the usual rental price is erratic and additional assumptions are usually made to ensure that it is not too erratic or even negative.

9 Note that $\mathbf{J}$ and $\mathbf{J}^{(-)}$ contained Γ and $\Gamma^{(-)}$ elements, respectively.

the matrix of the first derivatives of the demand system with respect to the information set satisfy a given rank condition.[10] Using Proposition 11 of Ouellette and Vigeant (2001b) and assuming that the regulation function is independent of the information set used by the firm, that is, $\mathbf{h}_J = 0$, it is possible to impose a priori the parameter restrictions required to recover the technology. Then, from Lasserre and Ouellette (1999) we deduce that the required rank condition is verified when the parameters satisfy the following restrictions:

$$\alpha_i^l = \frac{\alpha_q^l}{\nu_q}\nu_i \quad \text{for all } l \text{ and } i; \qquad \alpha_a^l = \frac{\alpha_q^l}{\nu_q}\nu_a \quad \text{for all } J_a; \tag{10}$$

$$\beta_{ii'}^l = \frac{\alpha_q^l}{\nu_q}\eta_{ii'} \quad \text{for all } l \text{ and } i; \qquad \beta_{iq}^l = \frac{\alpha_q^l}{\nu_q}\eta_{iq} \quad \text{for all } l \text{ and } i; \tag{11}$$

$$\beta_{ia}^l = \frac{\alpha_q^l}{\nu_q}\eta_{ia} \quad \text{for all } l \text{ and } i; \qquad \beta_{is}^l = \frac{\alpha_q^l}{\nu_q}\eta_{is} \quad \text{for all } l \text{ and } i; \tag{12}$$

$$\beta_{qs}^l = \frac{\alpha_q^l}{\nu_q}\eta_{qs} \quad \text{for all } l \text{and } i; \qquad \beta_{as}^l = \frac{\alpha_q^l}{\nu_q}\eta_{as} \quad \text{for all } l \text{ and } i; \tag{13}$$

where s stands for ϕ_r, k, y, and τ. With these restrictions imposed on the model, the estimated functions are conditional demands. An error term has been added to each demand equation (including investment) to account for optimization and measurement errors. We have conducted the estimation for each sector separately, resulting in fifteen distinct sets of estimated parameters.[11] The three factor demand equations and the investment function together form a system of seemingly unrelated equations that can be estimated with Zellner's iterative method (see Davidson and McKinnon 1993).

6. Technology measurement

The presence of additional constraints in the set up of our problem makes it impossible to use the standard direct substitution method for the recovery of the underlying technology. Ouellette and Vigeant (2000) have shown, however, that it is possible to recover the first derivatives of the production function from the optimality conditions. That is, the first derivatives of the production

10 For a detailled treatment of this question, the reader is referred to Ouellette and Vigeant (2000).
11 On average, there are 50 parameters per sector for a total of roughly 750 estimated parameters, so they are not reported here. They are, however, available upon request.

function can be written as a function of the partial derivatives of the system of demands as follows:[12]

$$\begin{bmatrix} \mathbf{f}_x^T \\ f_i^T \end{bmatrix} = \begin{bmatrix} \left(\mathbf{x}_y\mathbf{x}_y^T + \mathbf{x}_J\mathbf{x}_J^T + \mathbf{x}_\phi\mathbf{x}_\phi^T\right) & \left(\mathbf{x}_y i_y^T + \mathbf{x}_J i_J^T + \mathbf{x}_\phi i_\phi^T\right) \\ \left(i_y\mathbf{x}_y^T + i_J\mathbf{x}_J^T + i_\phi\mathbf{x}_\phi^T\right) & \left(i_y i_y^T + i_J i_J^T + i_\phi i_\phi^T\right) \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{x}_y \\ i_y \end{bmatrix} \tag{14}$$

and

$$\begin{bmatrix} f_k^T \\ f_t^T \end{bmatrix} = - \begin{bmatrix} \mathbf{x}_k^T & i_k^T \\ \mathbf{x}_t^T & i_t^T \end{bmatrix} \begin{bmatrix} \mathbf{f}_x^T \\ f_i^T \end{bmatrix}, \tag{15}$$

where $\mathbf{f}_x = [f_l \quad f_m \quad f_e]$ and f_k denote the marginal products of labour, materials, energy, and capital, respectively; f_i is the measure of the adjustment costs; and f_t measures the shift of the production function over time, that is, f_t is a measure of technological change. Note that the representation of the partial derivatives of the production function is in terms of partial derivatives of the demand functions, which means that estimation of the demands system provides an almost direct first characterization of the technology.

The first derivative of f with respect to i, that is, f_i, is a direct measure of internal adjustment costs. If it is negative, it signals that investment is costly.[13] For the firm, this means that new investment forces a reallocation of productive resources to the installation of new capital goods. This cost of reallocation is measured in terms of forgone output. On the other hand, a positive f_i means that current period investment becomes immediately productive. The value assumed by f_i can be directly calculated from the estimated input demand and investment functions. Since this derivative can easily be estimated, our model provides a method to empirically verify the existence of adjustment costs.

Returns to scale and the primal measure of technological progress are, respectively:

$$\text{RTS} = \sum_{l=1}^{n} \frac{f_{x_l} x_l}{f} + \sum_{j=1}^{m} \frac{f_{i_j} i_j}{f} + \sum_{j=1}^{m} \frac{f_{k_j} k_j}{f} \tag{16}$$

12 This representation of the marginal product holds if the input prices can identify the inputs. Formally, the matrix of partial derivatives,

$$\left[\frac{\partial \begin{bmatrix} \mathbf{w} + \boldsymbol{\mu}^T \mathbf{h}_x \\ q + \overline{C}_{k_1} + \boldsymbol{\mu}^T \mathbf{h}_i \end{bmatrix}}{\partial (\mathbf{w} \quad q)} \right],$$

is non-singular.

13 For a detailed discussion of adjustment costs, the reader is referred to Eisner and Strotz (1963) and Treadway (1969).

and

$$\frac{\dot{A}}{A} = \frac{f_t}{f}. \tag{17}$$

A summary of the results on technological measurement is presented in table 1. The first number on the line represents the average of the estimated measures over the sample, while the numbers in parenthesis are, respectively, the mid-sample value and the corresponding standard error.[14,15] We observe that f_i is positive on average in nine sectors.[16] Furthermore, four of these sectors, Non-Metallic Mineral Products, Metal Fabricating, Primary Metal and Furniture and Fixture did not experience any periods of costly adjustments in their stock of capital. These results warn us of the temptation of imposing adjustment costs a priori in a model in the absence of empirical evidence.

The average of the returns to scale and technological change measures are presented in table 1. The average of the returns to scale per industry are distributed around unity, ranging between 0.93 and 1.39, with the exception of the Petroleum and Coal Products Industries, which shows a value of 1.69.[17] Technological change averages around 1.8% per year.[18]

14 We have calculated standard errors and confidence intervals for all the measures reported in this paper. Those measures are calculated for every sample point and for this reason cannot be reported here. Alone, there are more than 9000 standard errors calculated (20 measures reported in this paper, to multiply by 15 sectors and 31 sample points). We have chosen to report the mid-sample point value and the corresponding standard error, so that the sample trend can be picked up. This presentation also provides a rough estimate of the typical confidence interval, something not possible when reporting only the average of both the variables and the standard errors. The entire set of estimates is available upon request.

15 We have used the delta-method to estimate confidence intervals for every measure presented in this paper (description of the technology in table 1, the impact of technological change and of the regulation in tables 3 and 4). The method is based on a first-order Taylor approximation of mostly highly non-linear functions of the estimated parameters (this is especially true for the measures presented in table 1). Consequently, the delta method cannot provide good and reliable standard errors, in general. Therefore, these standard errors are weak indicators of the reliability of our estimates.

16 Note that the first derivatives of the production function are unit dependant. This explains the somewhat important variability in size of f_i across sectors. This is especially apparent in the Food and Beverage sector. For this reason, the reader's attention should be on the sign of the measure. Note also that, based on our estimate of the standard errors, there are significant adjustment costs only in the following sectors: Food and Beverage (6 years), Chemical (16 years), Coal and Petroleum (7 years), Transportation Equipment (10 years) and Plastics and Rubbers (8 years).

17 Based on our δ-method estimates of the standard errors, the returns to scale are generally not significantly different than one. However, there is evidence of increasing returns to scale in Petroleum and Coal (11 years) and Clothing (18 years) and of decreasing returns to scale in Metal Fabricating (6 years) and Furniture (1 year).

18 A likelihood ratio test was used to test the hypothesis that the technological progress was not significantly different from zero in every sector. This assumption was massively rejected, since almost every p-value was equal to zero. Therefore, there is evidence that technological progress had an impact in every sector. Using our δ-method estimates of the standard error of $\dot{A}/A$ it is possible to conclude that virtually every sector has had periods of significant technological progress. The worse-case scenario is a long period with no significant technological progress. It is important to note also that no sector experienced a period of significant negative progress. The latter two results are based on 95% confidence intervals using the δ-method.

TABLE 1
Description of the technology (sample averages)[a]

	RTS	$\dot{A}/A$	f_i	*flex*	$\varepsilon_{flex,t}$
Food & Bev.	1.19	0.028	−8010.83	0.004	0.020
	(0.82, 0.289)	(0.026, 0.004)	(−5347, 2069)	(0.004, 0.001)	(0.020, 0.000)
Chemical	1.12	0.020	−0.84	0.001	−0.01
	(0.95, 0.562)	(0.026, 0.011)	(−1.11, 0.421)	(0.003, 0.001)	(−0.001, 0.000)
Petro. & Coal	1.69	0.023	−3.97	0.003	−0.20
	(1.39, 0.276)	(0.02, 0.010)	(−7.30, 2.753)	(0.001, 0.000)	(−0.04, 0.000)
Non-Met. Minerals	1.06	0.018	0.07	0.003	−0.14
	(1.11, 0.336)	(0.015, 0.003)	(0.07, 2.049)	(0.003, 0.005)	(−0.106, 0.000)
Electrical Prod.	1.04	0.025	1.63	0.0004	0.23
	(0.82, 0.193)	(0.016, 0.027)	(2.64, 2.974)	(0.000, 0.000)	(0.63, 0.000)
Transport. Equip.	1.17	0.008	−5.88	0.0004	−0.02
	(1.02, 0.172)	(0.028, 0.033)	(−5.357, 2.608)	(0.001, 0.000)	(−0.13, 0.000)
Machinery	1.19	0.023	5.98	0.001	−0.39
	(1.14, 0.290)	(0.017, 0.007)	(1.27, 6.865)	(0.001, 0.000)	(−0.24, 0.000)
Metal Fabricating	0.96	0.018	0.61	0.002	−0.01
	(0.93, 0.062)	(0.015, 0.011)	(0.61, 1.54)	(0.001, 0.000)	(−0.01, 0.000)
Primary Metal	1.35	0.002	0.36	0.001	−0.04
	(1.31, 15.19)	(0.002, 0.110)	(0.32, 4.33)	(0.001, 0.001)	(−0.03, 0.000)
Paper	1.27	0.052	−0.07	0.001	−0.04
	(1.65, 1.108)	(0.061, 0.036)	(−1.111, 2.265)	(0.001, 0.000)	(−0.04, 0.000)
Furniture	0.93	−0.003	3.92	0.019	−0.02
	(0.97, 0.087)	(0.011, 0.019)	(2.70, 3.737)	(0.016, 0.006)	(−0.02, 0.000)
Wood	1.37	0.046	0.21	0.002	0.00
	(1.17, 0.231)	(0.045, 0.009)	(0.02, 0.884)	(0.004, 0.002)	(0.62, 0.000)
Textile	1.39	0.015	2.47	0.009	−0.13
	(1.19, 0.448)	(0.010, 0.033)	(2.71, 7.821)	(0.007, 0.001)	(−0.09, 0.000)
Plastics & Rubber	1.17	0.018	1.20	0.012	−0.04
	(1.37, 0.237)	(0.029, 0.028)	(−3.40, 1.644)	(0.005, 0.003)	(−0.04, 0.000)
Clothing	1.26	0.017	−0.45	0.003	−0.18
	(1.21, 0.090)	(0.015, 0.002)	(−0.45, 1.782)	(0.002, 0.001)	(−0.17, 0.000)

a The numbers in parenthesis are the mid-sample value and its standard error, respectively.

Technological change has an indisputable effect on the input mix used by the firm, since it alters the production process. The sample average of the elasticity estimates for investment are reported in table 3 below.[19] Six sectors have positive technological change elasticities of investment, and technological change led to a reduction in energy demand in a third of the sectors. For 11 of the sectors technological change has induced cost savings. Technological change has induced increasing costs over the entire sample in only one sector (Wood Industries). All other sectors experienced periods of decreasing costs. Also note that in all sectors but the Wood Industries, employment reduction was associated with technical change.

In the context of a changing environment for the firm, it is interesting to analyse how decisions regarding technology allow the firm to adjust its cost as the level of output varies. The choice of technology reflects the firm's flexibility.

The measure of flexibility is defined as the second derivative of the average cost with respect to y. That is, let the average cost function be $CM(y) = C(y)/y$; then

$$flex = CM_{yy} = \frac{1}{y^3}[y^2 C_{yy} - 2yC_y + 2C]. \tag{18}$$

Such measures are always positive. A value close to zero indicates a flexible firm, since the curvature of the average cost function is small. This can be interpreted as saying that if output increases marginally, unit costs will not increase by much. A flexible technology in the sense of Stigler (1939) means that even when the output of a firm is volatile, unit production costs remain fairly constant over a large range of output levels. A firm with low flexibility is bound to see substantial increases of its unit cost for similar variations of the output level. Furthermore, when output is very volatile, such a technological choice is compatible with important unit cost variations. Therefore, observations on output volatility along with flexibility measures provide a good indicator of potential technological change. In our empirical model, the flexibility measure is given by

$$flex = \frac{1}{y^3}[y^2(\mathbf{w}^T\mathbf{x}_{yy}) - 2y(\mathbf{w}^T\mathbf{x}_y) + 2\mathbf{w}^T\mathbf{x}], \tag{19}$$

where $\mathbf{x} = [x_1 \quad x_2 \quad x_3]$, which are, respectively, labour, materials and energy.[20]

19 The effect of technological progress on costs and inputs is measured via the respective cost and input technological progress elasticities (i.e., $\varepsilon_{Ct} = (\partial C/\partial t)(1/C)$ and $\varepsilon_{x_i t} = (\partial x_i/\partial t)(1/x_i)$). Those results are available upon request.

20 The flexibility measure reported in this paper is calculated based on the variable cost. It is also possible to obtain a measure of flexibility by including investment expenses. The results, however, do not differ significantly from the measure we used.

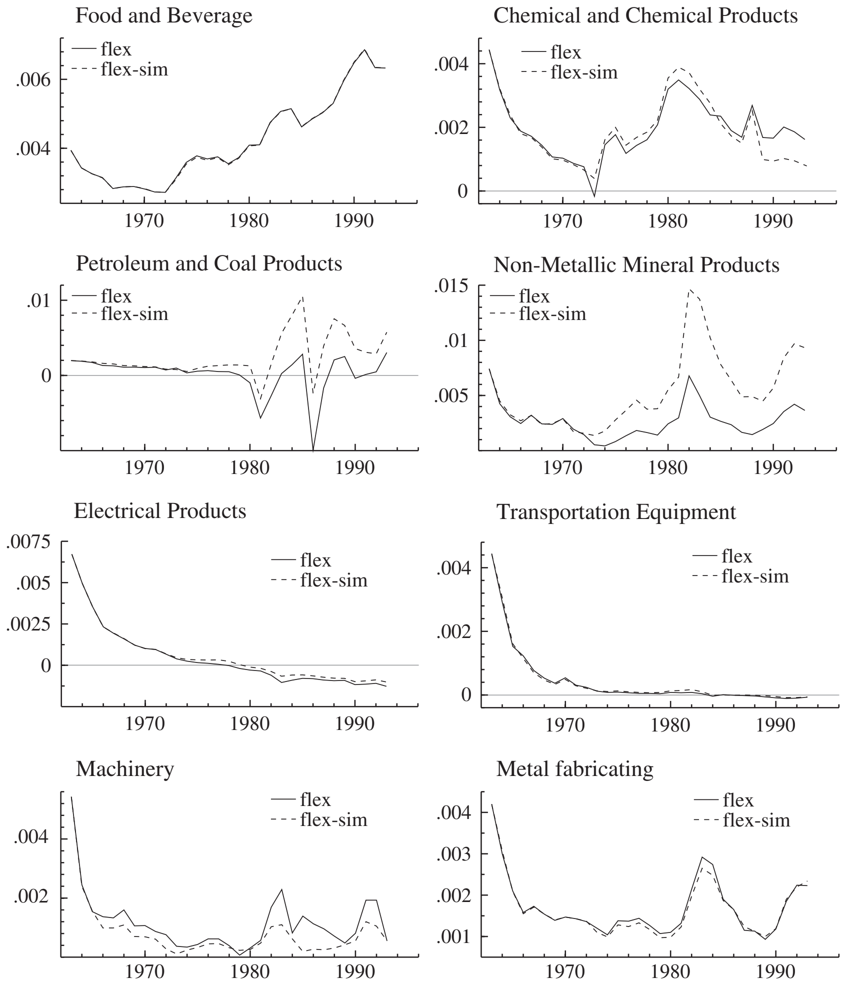

FIGURE 2 Measured and simulated flexibility

The average of these variables are presented in table 1[21] and plotted in figures 2 and 3.[22] From these graphs we clearly see that flexibility improved between 1963 and 1972 for all sectors but Wood and Textile Industries. To characterize

21 As mentioned above, standard errors were calculated for all observation using the δ-method. Using those estimates, it is possible that the vast majority of the flexibility estimates are significantly positive in all but two sectors (Non-Metallic Minerals and Primary Metal).

22 The solid line on those figures represents the flexibility measures calculated from equation (19). The concepts related to the measure represented by the dashed line on those figures will be discussed below.

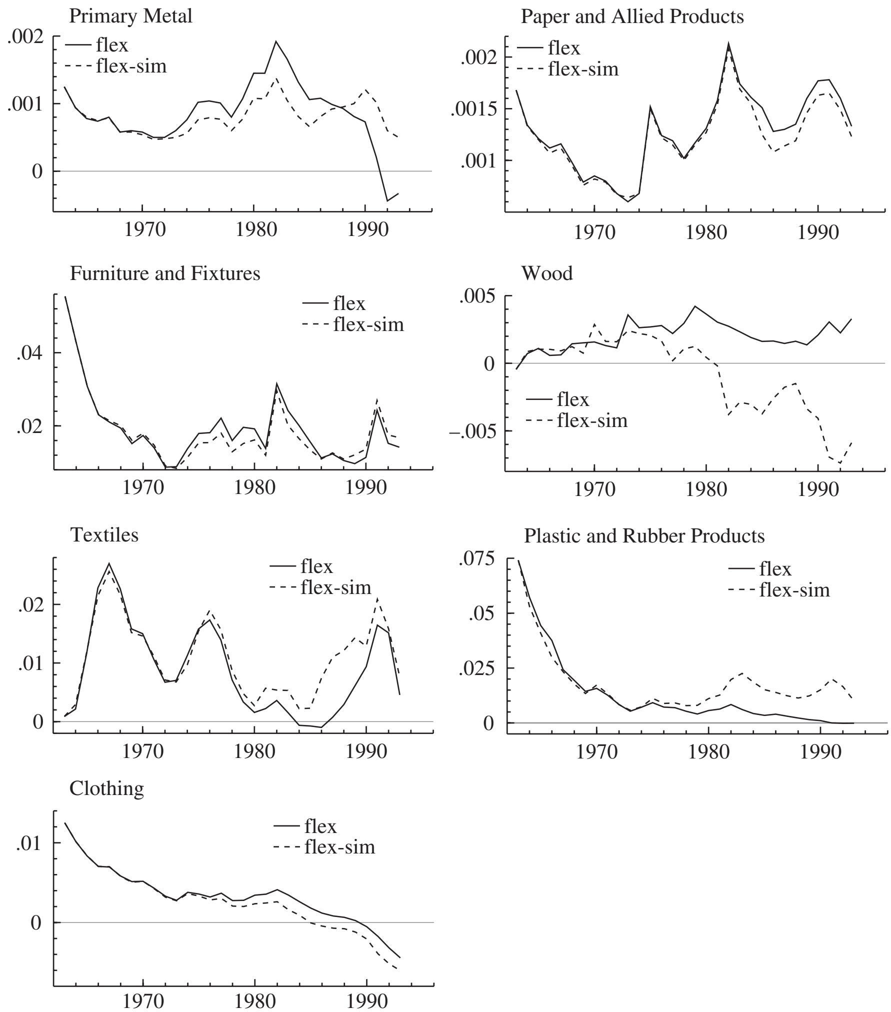

FIGURE 3 Measured and simulated flexibility

the evolution of the flexibility after 1973, it is preferable to group the sectors. The first group is characterized by industries showing increasing flexibility over the entire sample. This group includes the Electrical Products, Transportation Equipment, Rubber and Plastics Products, and Clothing Industries. With the exception of Clothing Industries, these are high-technology sectors. In the second group, we find sectors that experience improvements flexibility at the beginning of the sample followed by a period of increased volatility of the measure (in particular, during the 1980s). This group includes Petroleum and Coal Products, Non-Metallic Mineral Products, Machinery, Metal Fabricating, and Furniture and Fixture Industries. The third group is composed of the industries that show an improved flexibility at the beginning of the sample period followed by a period of deterioration. Such deterioration in terms of flexibility is usually accompanied by a higher volatility of the measure. The industries in this category are Food and Beverage, Chemical and Chemical Products, and Paper and Allied Industries. Industries in the last group, formed by Primary Metal, Wood, and Textile Industries, do not exhibit any specific identifiable behaviour. While Textile Industries show some occasional improvement, there are three major peaks in 1967, 1976, and 1992 that prevent us from concluding that the flexibility of the sector exhibits any tendency to improve. The Wood Industries show deteriorating flexibility early in the sample, followed by some improvement after 1979. Finally, the Primary Metal Industries exhibit a major deterioration in flexibility from 1972 until 1984, following sustained improvement between 1963 and 1972. After 1984 the flexibility has continuously improved until 1992. From these results it is clear that the choice of flexibility varies by sector. The nature of the particular sector is important in terms of this aspect of technological choice.

The effect of technological change on flexibility is given by

$$\begin{aligned}\varepsilon_{flex,t} &= \frac{\partial \ln (flex)}{\partial t} = \frac{\partial \ln CM_{yy}(y)}{\partial t} \\ &= \frac{\dot{B}}{B} + \frac{CM}{y^2 CM_{yy}} \left[\frac{\partial}{\partial \ln y} \left(\frac{\partial \varepsilon_{cy}}{\partial t} \right) + \frac{\partial \varepsilon_{cy}}{\partial t} (2\varepsilon_{cy} - 3) \right], \qquad (20)\end{aligned}$$

where $\dot{B}/B = \partial \ln CV/\partial t$ is the dual technological progress, and $\varepsilon_{cy} = \partial \ln CV/\partial \ln y$ is the cost-output elasticity. This measure can be intuitively interpreted as the sum of two distinct components. The first component is the dual technological progress, which represents the decrease in costs resulting from technological progress. The second component is a function of the time derivative of the cost-output elasticity. The estimate of this technological progress elasticity of flexibility is negative in twelve sectors (see table 1). These results indicate that technological progress induces firms to increase the flexibility of their technology, since it reduces the curvature of their average costs. Thus, when changing their production technology, firms will prefer to adopt more flexible processes. This suggests that defence against a volatile output path is an important component when a new technology is selected.

7. Impacts of regulation

In this section we will analyse the impacts of international trade and environmental regulations. Environmental regulation was initially introduced in the 1960s and has continued to develop since then. On the other hand, international trade regulation has experienced two distinct phases in Canada. In the 1970s the trade

TABLE 2
Tests of the impact of additional constraints

	Test 1 Overall		Test 2 International		Test 3 Environmental		Test 4 Investment	
	L.R.	P-value	L.R.	P-value	L.R.	P-value	L.R.	P-value
Food & Bev.	102.75	0.000	46.37	0.000	84.34	0.000	30.17	0.000
Chemical	76.98	0.000	20.86	0.008	60.89	0.000	19.72	0.001
Petro & Coal	131.13	0.000	92.23	0.000	40.22	0.000	13.802	0.017
Non Metal. Min.	28.02	0.001	9.38	0.052	10.15	0.038	2.48	0.290
Electrical Prod.	171.26	0.000	7.50	0.112	133.03	0.000	35.67	0.000
Trans. Equip.	63.51	0.000	40.16	0.000	24.07	0.002	12.78	0.012
Machinery	71.46	0.000	43.46	0.000	37.70	0.000	12.59	0.014
Metal Fabric.	46.12	0.000	29.70	0.000	20.81	0.000	14.59	0.001
Primary Trans.	54.96	0.000	34.05	0.000	29.08	0.000	27.06	0.000
Paper	79.49	0.000	49.33	0.000	32.76	0.000	34.89	0.000
Furniture	78.24	0.000	43.38	0.000	33.34	0.000	11.21	0.024
Wood	81.74	0.000	49.70	0.000	34.94	0.000	25.60	0.000
Textile	50.24	0.000	22.13	0.005	40.13	0.000	12.58	0.014
Plastics & Rubber	151.27	0.000	100.58	0.000	100.95	0.000	28.90	0.000
Clothing	32.83	0.000	12.15	0.016	22.93	0.000	11.14	0.004

regulation focused on the protection of Canadian ownership of productive assets. This lasted until the mid 1980s. After the change of government in 1984, the policies introduced by the Tories were redirected to favour foreign investment and open trade. This led to the Free Trade Agreement with the United States.

For empirical purposes, the strength of the environmental regulation is proxied by the budget of the department of environment. This is done in order to capture monitoring and regulation enforcement. The international trade policy of the federal government has been characterized by a period of protectionism of the Canadian firms while FIRA was in effect (between the mid-1970s and mid-1980s) followed by a period of open trade and invitations to foreign capital to migrate into Canada. Our international trade variable is therefore modelled as a polytomic variable to capture the different phases of the policy.

The first step in our analysis is to test the impact of the additional constraints on the decision process of the firms (i.e. the conditional demands). Table 2 presents the results of likelihood ratio tests of four hypotheses corresponding to specific impacts of regulation. The first hypothesis test is used to verify that the regulation variables have an overall effect. The second hypothesis test concerns the relevance of the international trade conditions. The third test has to do with the effect of the environmental variable. Finally, we test the combined effect of both sets of regulatory constraints on investment. In all cases the null hypothesis is that the additional variables have no effect on firm's decisions. The additional constraint variables have a significant impact in all sectors. The international trade variable is not significant at the 5% level in the case of the Non Metallic Mineral and Electrical Products Industries, and we cannot reject the null hypothesis that investment was not affected by regulation in the case of the Non Metallic Minerals Industry only, also at the 5% level.

We use two points of view to analyse the effects of regulation: a 'local' and a 'global' approach. We will begin with a local approach that consists in measuring the regulation elasticities of demand and cost. We will conclude with a global analysis of the regulations. The latter approach consists of a simulation of the evolution of the factor demands, investment, capital, and flexibility in a regulation-free environment.

7.1. Local effects

The impact of the additional constraints on factor demands and costs are measured by the regulation elasticities of demand and of cost, respectively.[23] A summary of the results (the sample average of the elasticities, the mid-sample value and the corresponding standard error) regarding these measures for investment is found in table 3.

The results suggest that international trade policies between the mid-1970s and the mid-1980s have been unfavourable to employment and investment, with employment decreasing in 12 sectors and investment falling in 13 sectors. The FTA did not have a clear-cut effect on employment, since there were increases in employment in seven sectors and decreases in the other eight. It has also had a positive effect on investment in eight sectors. Note that in all sectors where the FTA had a positive effect, FIRA had a negative effect, with the exception of Food and Beverage Products. Both policies had a combined negative impact on investment in only five sectors. Metal Fabricating Industries was the only sector to gain from both FIRA and FTA.

The effects of environmental policies are more difficult to interpret with a static analysis. The environmental regulation elasticity of energy demand is positive in two-thirds of the sectors. The negative environmental regulation elasticity of investment suggests that the policy did not provide an incentive for manufacturing firms to invest in energy saving equipment. However, this conclusion is not as clear-cut in the 'global' analysis, which suggests that Canadian environmental policy did not induce a significant reduction in either energy consumption in the manufacturing sectors or investment in energy-saving capital.

23 The regulation elasticities of the demands are given by

$$\varepsilon_{x_l \phi_r} = \frac{\partial \widehat{x}_l}{\partial \phi_r} \frac{\phi_r}{\widehat{x}_l} \qquad l = 1, 2, 3, 4 \text{ and } r = 1, 2,$$

where x_1 is labour, x_2 is materials, x_3 is energy, x_4 is investment, ϕ_1 is the international trade variable, and ϕ_2 is the environmental regulation variable. We report only the elasticities for investment; the others are available upon request.

TABLE 3
Impacts of technological change and regulation on investment (sample averages)[a]

	ε_{It}	$\varepsilon_{I,FIRA}$	$\varepsilon_{I,FTA}$	$\varepsilon_{I,ENVIRO}$
Food & Bev.	0.65 (2.587, 0.473)	0.061 (0.087, 0.058)	0.090 (0.094 0.034)	0.006 (−0.226, 0.098)
Chemical	1.37 (2.81, 0.567)	−0.116 (−0.127, 0.089)	−0.171 (−0.114, 0.087)	0.972 (1.499, 0.211)
Petro. & Coal	−2.17 (−3.04, 2.192)	−0.168 (−0.251, 0.836)	−0.238 (−0.329, 1.237)	−1.649 (−0.997, 0.296)
Non-Met. Mineral	−0.71 (−0.711, 0.304)	−0.228 (−0.155, 0.108)	0.234 (0.232, 0.161)	−0.015 (−0.016, 0.016)
Electrical Prod.	−0.51 (−1.44, 0.518)	−0.082 (−0.090, 0.070)	0.030 (0.030, 0.024)	−0.172 (−0.374, 0.108)
Transport. Equip.	0.78 (1.01, 2.083)	−2.129 (−2.620, 1.396)	−0.769 (−0.813, 0.329)	−0.494 (−1.489, 1.132)
Machinery	−1.59 (−1.61, 0.561)	−0.197 (−0.178, 0.165)	0.280 (0.280, 0.129)	−0.272 (−1.186, 0.416)
Metal Fabricating	−0.01 (−0.01, 0.513)	0.355 (0.311, 0.097)	−0.332 (−0.293, 0.086)	−0.443 (−0.746, 0.215)
Primary Metal	−0.51 (−0.59, 0.237)	−0.696 (−0.563, 0.091)	0.530 (0.398, 0.059)	0.377 (0.433, 0.159)
Paper	−2.60 (−4.48, 1.754)	−1.363 (−1.839, 0.873)	0.439 (0.477, 0.307)	−0.861 (−2.721, 0.918)
Furniture	−0.59 (−0.79, 0.528)	−1.128 (−1.270, 0.419)	−0.068 (−0.064, 0.200)	−0.348 (0.006, 0.203)
Wood	10.66 (9.86, 1.505)	−0.029 (−0.019, 0.100)	0.712 (0.880, 0.213)	−0.505 (−0.419, 0.182)
Textile	−4.90 (−7.749, 2.657)	−1.000 (−1.237, 0.457)	−0.586 (−0.536, 0.335)	0.082 (0.712, 0.340)
Plastics & Rubber	0.02 (−1.53, 0.624)	−0.168 (−0.257, 0.117)	0.520 (0.720, 0.163)	−0.980 (−1.063, 0.295)
Clothing	0.003 (0.004, 0.618)	−0.173 (−0.180, 0.104)	0.100 (0.104, 0.056)	−0.143 (−0.267, 0.290)

a The numbers in parenthesis are the mid-sample value and its standard error, respectively.

Since the additional constraints affect firm behaviour, they also have an impact on technological choices. They are therefore likely to influence flexibility choices. The effect of regulation on flexibility can be analysed by the same procedure used to measure the effect of technological change on flexibility.[24] A negative elasticity indicates that a marginal change in the regulation will reduce the value of *flex*, inducing a reduction of the curvature of the average cost function, inducing the choice of a more flexible technology. The

24 The elasticity is given by

$$\varepsilon_{FLEX,\phi_r} = \frac{\partial \ln (FLEX)}{\partial \ln \phi_r} = \frac{\partial \ln CM_{yy}(y)}{\partial \ln \phi_r}.$$

TABLE 4
Impact of the additional constraints on flexibility (sample averages)[a]

	$\varepsilon_{flex,FIRA}$	$\varepsilon_{flex,FTA}$	$\varepsilon_{flex,ENVIRO}$
Food & Bev.	−0.008	0.001	0.000
	(−0.007, 0.000)	(0.001, 0.000)	(−0.001, 0.000)
Chemical	−0.081	0.472	0.003
	(−0.367, 0.000)	(0.445, 0.000)	(0.002, 0.000)
Petro. & Coal	−2.097	−2.530	1.662
	(−1.647, 0.001)	(−3.258, 0.001)	(−0.358, 0.000)
Non-Met. Mineral	0.420	−0.395	0.596
	(0.327, 0.000)	(−0.408, 0.001)	(0.558, 0.000)
Electrical Prod.	−0.339	0.033	−0.452
	(−0.371, 0.000)	(0.031, 0.000)	(−1.061, 0.000)
Transport. Equip.	1.168	−0.335	0.353
	(1.523, 0.000)	(−0.327, 0.000)	(0.719, 0.000)
Machinery	3.265	1.709	1.383
	(2.414, 0.000)	(1.030, 0.001)	(1.270, 0.000)
Metal Fabricating	−0.103	0.141	0.047
	(−0.102, 0.000)	(0.138, 0.000)	(0.076, 0.000)
Primary Metal	−0.077	0.070	−0.137
	(−0.064, 0.000)	(0.606, 0.000)	(−0.144, 0.000)
Paper	0.241	0.103	−0.012
	(0.224, 0.000)	(0.108, 0.000)	(0.007, 0.000)
Furniture	0.050	0.351	−0.318
	(0.038, 0.001)	(0.261, 0.002)	(−0.600, 0.001)
Wood	−0.024	−1.000	−0.644
	(−0.001, 0.000)	(−0.956, 0.001)	(−0.451, 0.000)
Textile	0.058	0.336	−0.016
	(0.397, 0.001)	(0.171, 0.003)	(−0.008, 0.000)
Plastics & Rubber	0.459	−3.982	12.529
	(0.468, 0.002)	(−22.889, 0.003)	(−0.610, 0.002)
Clothing	0.056	−0.003	−0.064
	(0.051, 0.0001)	(0.153, 0.0002)	(−0.069, 0.0001)

a The numbers in parenthesis are the mid-sample value and its standard error, respectively.

results are reported in table 4. In all sectors except Coal and Petroleum Products, Transportation Equipment, and Metal Fabricating, the sectors' reactions are inelastic. The additional constraints did not have a systematic effect on the flexibility of the firm. More or less half of the sectors saw their flexibility increase, while the other half experienced a decrease. Note, however, that the FTA was an exception, since it had a negative impact on nine sectors. This may be due to the fact that the FTA is new and that the introduction of new technology is not yet complete.

7.2. *Global effect*

The global method proposed here removes the regulation variables from the demand equations and allows us to characterize the behaviour of the firm as if the regulation had not been in place. To implement the method, regulation parameters have been set to zero in the regression equations. Taking into account the accumulation and depreciation of capital and the dynamics of factor demands, we generate investment, input, and capital series. These new series are interpreted as the decisions of the manufacturing sector in a regulation-free environment. This method of simulating the impact of regulation and changes in the firm's environment assumes implicitly that the input and output prices are not affected by the removal of the regulatory constraints. The Canadian economy is fairly open, so that many prices are set in international markets, where Canada has little or no power. Thus, it is plausible that the impact of variations in regulation on the Canadian prices would be low. Thus, all simulations are conducted using the observed prices.

Figures 4 and 5 show the evolution of the actual and regulation-free series for capital. The simulated capital series exhibits three stylized behaviours across the various sectors. The first is an over-capitalization; a firm will accumulate more capital than it would have done if there were no regulatory variables. The second case is under-capitalization. Finally, some sectors may exhibit periods of both overcapitalization and undercapitalization.

Although almost all sectors experienced periods of over- and under-capitalization, in eleven sectors there are clear trends: In five there was general over-capitalization and in six there was under-capitalization. For the remaining four sectors no clear pattern emerged. It is interesting to note that after 1989 the results of the simulation show that 8 of the 15 industries have invested more than they would have without the (environmental and FTA) regulation. In the Clothing Industries, the late 1980s are characterized by an increase in investment, while the regulation-free series tends to stabilize and eventually decrease. In almost every sector the period that exhibits the greatest differences in terms of the accumulation of capital is the 1970s. Outside that period, the evolutions of both series (observed and regulation free) are parallel,[25] in contrast to the abrupt surges or falls evident during the 1970s. This suggests that the development of environmental policy and international policies of the government at the beginning of the FIRA mandate did affect firm behaviour. By performing simulations using one regulation variable at the time, we observe that the period covering the mandate of the FIRA is associated with lower investment levels than would have been in place without the policy in nine sectors. Impacts on investment levels were clearly positive in only three sectors.

This decomposition of the effects by variable shows that investment was positively affected by the FTA in seven sectors. Environmental policy had a positive effect in seven sectors, affecting investment negatively in only half of

25 Exceptions are Food and Beverage, Primary Metal, Paper and Allied Products and Clothing Industries. Although there was a jump in the series in the 1970s, there was a change in trend in the 1980s with the series starting to go in the opposite direction to the original.

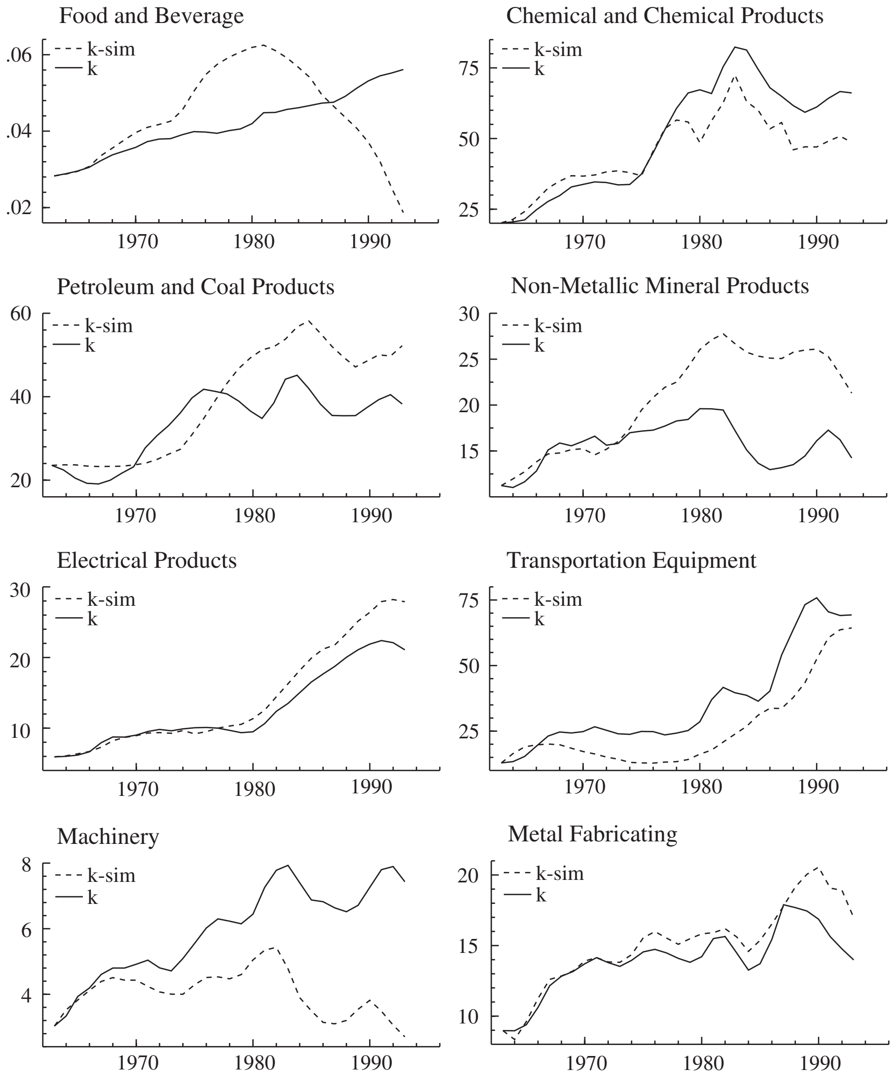

FIGURE 4 Observed and simulated capital stock

the sectors. The most important characteristics, however, are the one-time changes in investment levels at the beginning of the 1970s (be it negative or positive). Most sectors adjusted to the new policy once in the 1970s (and a few in the 1980s). Thereafter, a gap persisted between the observed and regulation-free capital stocks. Even though the specific reactions to the regulation are different in each sector, with various signs and sizes of the impacts, the timing of the changes is similar across sectors. For instance, there is a one-time jump

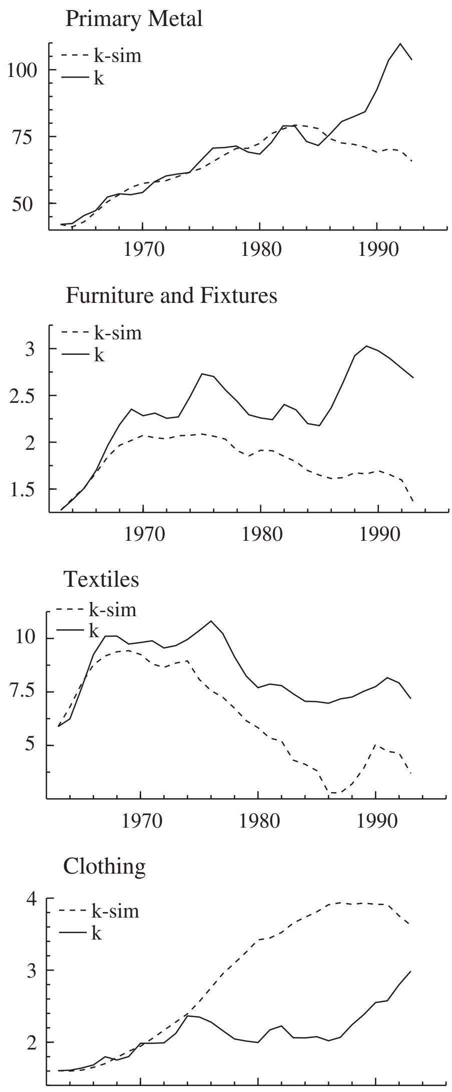

FIGURE 5 Observed and simulated capital stock

in the level of investment in virtually all sectors during the 1970s. Although not as systematic, there was also an amplification of the impact of regulation in the late 1980s as a consequence of FTA.

As in the case of capital and investment, it is possible to simulate the flexibility measures with the regulation parameters set to zero. The values of the demands, investment function, and capital series generated above can be substituted into the flexibility equations to obtain measures of the choice of flexibility for the industries in a regulation-free environment. Figures 2 and 3 present both the regulation-free measures and their observed counterparts.

As identified previously, the effect of the regulation on the flexibility is of a small order in general. Regulation seems to have no impact on flexibility choices in the Food and Beverage and Transportation Equipment Industries. Regulation induced the firms to adopt more flexible technology in five sectors, while it had the opposite effect in six other sectors. The decomposition by type of regulation reveals, however, that international policies had a negative impact on flexibility, while flexibility improved in more sectors than not under the effect of environmental policy.

8. Conclusion

This paper was conceived with the belief that firms react to changes in their environment, and changes that are not reflected immediately in observed input and output prices. The changes in the firms' environment materialize into technological changes that are realized through new investment. Consequently, the model used to analyse the behaviour of the manufacturing sector was a dynamic model of the firm characterized by a general expectation formation process and additional constraints that were used to account for environmental regulation changes faced by the firms.

To evaluate the effect of these additional constraints two methods were used. A traditional approach allowed us to directly estimate the effect of regulation by differentiating the demand functions with respect to the relevant economic environment variables. This allowed us to identify certain systematic behaviours. Among these, we noted that environmental policy failed to initiate any reduction of energy consumption in the manufacturing sectors and that the period of high international protectionism characterized by the FIRA had a predominantly negative impact on investment, since the rate of capital accumulation was reduced in reaction to this policy.

The flexibility analysis undertaken was intended to gauge the capacity of firms to adjust to changes in output. This provides an estimate of how technology is adapted to variations in output. The results indicate that industries with high flexibility belong to the group of high-technology sectors in the economy. However, to obtain a complete understanding of the flexibility of a firm, one has to consider the entire stream of costs and base the measure on the value of the program the firm must solve. This is so because a firm can be flexible, even though this flexibility might not be captured through a one-period measure. In fact, the firm may elect to modify its technology at each period in time, since this may be less costly than maintaining a technology that is flexible according to the one-period measure used here. Thus, it is desirable to be able to discriminate between possible manifestations of the flexibility choice made by the firms.

This paper contributes to the literature on the consequences of changes in regulation on the technological choices of the firms. Because the environment of the firm enters into the optimization problem under the form of either behavioural constraints or an information set, both the investment decision and the choice of production technology are affected by variables other than prices. The empirical results seem to confirm that our approach aids in the understanding of why prices alone are not able to fully explain the variability of investment. Thus, the entire dynamics of the firm's problem are affected by changes in the firm's circumstances, including its ability to adjust, and its flexibility. Changing the landscape surrounding the firm beyond simply the prices it faces ultimately means that its behaviour will be affected. The evidence gathered in our empirical exercises are sufficient to lead to the conclusion that this is not just a suspicion, but merely a reality.

Appendix: Data

The data are constructed from annual (1962–93) observations of fifteen Canadian Manufacturing Sectors. Changes have been made in the classifications of activities over the sample period. This necessitated a number of computations in order to adapt the data into a consistent set of series under a compound of the Classification of Economic Activities of 1970 and the Standard Industrial Classification of 1980. Details of these adjustments are available upon request.

A.1. Prices and quantities

Labour, materials, energy, and output data are taken from Statistics Canada, Catalog 31-203. In particular, the levels of output and materials are obtained by dividing the total expenditure for these categories by the appropriate price index. The price indices that have been used are the sectorial price index from Statistics Canada Catalog 62-011 to deflate output, and the gross national product (GNP) deflator, from Catalog 13-201 and 13-531, to deflate materials. It is implicitly assumed that the composition of the materials is more or less identical to that of the GNP.[26] The labour series was obtained by dividing salaries and wages by a price index built as follows: assuming that manufacturing-activity workers spend about the same time at work as their white-collar colleagues, the average hours paid per worker is deduced from the average hours worked by blue-collar workers. The total number of hours worked is the

26 This was not appropriate for the Coal and Petroleum industry, as materials consists mainly of coal and oil in that sector. We have used the price of crude petroleum, I193605, from Statistics Canada.

number of hours worked multiplied by the total number of employees. Finally, the wage rate is the result of the division of wage and salaries by total hours. All data used to compute the price index are obtained from Statistics Canada Catalog 31-203. The energy series is the deflated cost of fuel and electricity (Catalog 31-203). The price index for energy is calculated as follows: for the period 1962–84, a Divisia index is calculated based on the quantities and prices (Catalogs 57-506 and 57-208). Publication of Catalog 57-208 ceased after 1984, so for the period 1985–93, the price index is calculated as

$$\ln(ipe_t) = \ln(ipe_{t-1}) + \sum_j S_j(1984)(\ln w_{jt} - \ln w_{jt-1}), \tag{A1}$$

where $S_j(1984)$ is the share, in 1984, of type of energy j, and w_{jt} is the price index of the corresponding category of energy (Statistics Canada, Catalog 62-011).

Investment and capital for each sector are obtained from Statistics Canada, Catalog 13-568. The stock of capital is the end-of-the-year stock lagged one period, calculated using geometric depreciation. The effective purchasing price of capital goods is calculated as

$$q_t = p_{it}[(1 - cr_t)(1 - \tau_t z_t)]/(1 - \tau_t), \tag{A2}$$

where p_{it} is the implicit deflator of investment; cr_t is the rate of the investment tax credit;[27] and τ_t is the corporation benefit average tax rate. The data are from Fiscal Statistics, part 2- Corporations, Department of National Income, Tax Division, Catalog 61-208, Statistics Canada, and Financial and Fiscal Statistics for the enterprises, CC14. Finally, z_t is the present value of the tax deductible provision for depreciation for a marginal investment at time t. That is:

$$z_t = \alpha_t(1 + r_t)/(\alpha_t + r_t), \tag{A3}$$

where r_t is the interest rate,[28] α_t is the capital cost allowance rate, a weighted average of the prevailing rate for the different capital components (5% for the buildings and 20% for machinery). Table A1 contains descriptive statistics on investment and its price for each sector.

27 Taken from Catalog 61-208 of Statistics Canada and Financial and fiscal statistics for enterprises 1988–93, CC14, November 1995.

28 The interest rate is calculated from two monthly series: Bank of Canada series B14016-Average rate of return on ten Canadian industries and B14049-corporation interest rate, Scotia McLeod.

TABLE A1
Investment descriptive statistics

	Investment				Investment price			
	X	σ	Min	Max	X	σ	Min	Max
Food and Bev.	992	333	523	1635	0.77	0.24	0.36	1.10
Chemical	1324	617	386	2641	0.77	0.25	0.34	1.10
Petro. & Coal	639	299	113	1373	0.89	0.43	0.31	1.64
Non-Met. Minerals	386	124	182	610	0.73	0.30	0.32	1.19
Electrical Prod.	463	285	131	941	0.96	0.23	0.53	1.32
Transport. Equip.	1250	928	306	3254	0.70	0.27	0.30	1.03
Machinery	173	68	75	326	0.87	0.21	0.42	1.17
Metal Fabricating	383	114	179	764	0.74	0.27	0.32	1.08
Primary Metal	1492	560	747	3049	0.78	0.35	0.31	1.44
Paper	1965	1173	763	5887	0.80	0.33	0.34	1.37
Furniture	55	20	19	101	0.75	0.26	0.32	1.09
Wood	508	205	190	1097	0.74	0.30	0.33	1.40
Textile	235	59	128	358	0.75	0.28	0.33	1.17
Plastics and Rubber	335	161	101	787	0.69	0.28	0.29	1.02
Clothing	61	21	36	112	0.85	0.22	0.47	1.12

A.2. Information sets and additional restrictions variables

The regulation variables are constructed as follows. The international trade variable is constructed in a manner to capture the tightness of the international trade conditions in Canada. It assumes the value minus one (−1) during the mandate of the FIRA, between 1974 and 1984. After the signature of the FTA it assumes the value one (1). The environmental regulation variable is the deflated budget of the federal department of environment (Catalogs 68-512

TABLE A2
Information variables

	J_1	J_2	J_3	J_4	J_5	J_6	J_7	J_8
Food & Bev.	w_{Lt-1}	q_{t-1}	r_{t-1}					
Chemical	$bruita_t$	$pibk_{t-1}$						
Petro. & Coal	w_{Lt-1}	q_{t-1}	w_{Mt-1}	w_{Et-1}	$bruita_t$	ne_{t-1}	$pibk_t$	$pibk_{t-1}$
Non-Met. Mineral	$bruita_t$	k_{t-1}	$pibk_{t-1}$					
Electrical Prod.	w_{Lt-1}	q_{t-1}	w_{Mt-1}	w_{Et-1}	r_{t-1}	$pibk_{t-1}$		
Transport. Equip.	w_{Lt-1}	q_{t-1}	w_{Mt-1}	w_{Et-1}				
Machinery	w_{Lt-1}	q_{t-1}	w_{Mt-1}	w_{Et-1}				
Metal Fabricating	w_{Lt-1}	q_{t-1}	w_{Mt-1}	w_{Et-1}				
Primary Metal	w_{Lt-1}	q_{t-1}	w_{Mt-1}	w_{Et-1}				
Paper	q_{t-1}	r_{t-1}						
Furniture	w_{Lt-1}	q_{t-1}	cho_{t-1}	$pibk_{t-1}$				
Wood	w_{Lt-1}	q_{t-1}	w_{Mt-1}	$pibk_{t-1}$				
Textile	q_{t-1}	w_{Mt-1}	w_{Et-1}	$bruita_t$				
Plastics & Rubber	w_{Lt-1}	q_{t-1}	w_{Mt-1}	w_{Mt-1}	cho_t	cho_{t-1}	$pibk_t$	$pibk_{t-1}$
Clothing	w_{Lt-1}	q_{t-1}	w_{Mt-1}	w_{Et-1}	$bruita_t$			

and 68-211). We suppose that, as the budget of the department increases, the regulation is more stringent and enforced by some costly monitoring activities.

The information sets are specific to each sector, since the relevant variables are necessarily different for each industry, depending on the nature of the production activities. The information set for each sector is consequently a subset of the following variables: the lagged input price, w_{Lt-1}, w_{Mt-1}, w_{Et-1}, and q_{t-1} the discount factor $\rho_t = 1/(1+r_t)$, the output price lagged one period, p_{yt-1} or the lagged output level, y_{t-1},[29] the lagged stock of capital, k_{t-1}, the lagged number of firms in the industry, ne_{t-1}, current and lagged real gross national product, $pibk_t$ and $pibk_{t-1}$, lagged interest rate r_{t-1}, current and lagged unemployment rate, cho_t and cho_{t-1}, and the variance over two years of (monthly) output price, $bruita_t$. The information sets for each sectors are given in table A2.

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