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How Does Energy-Cost Lead to Energy Efficiency? Panel Evidence from Canada

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Abstract

An increase in energy-cost can induce energy efficiency improvement – a reduction in energy-output ratio. There are well-established theoretical conjectures of how this can take place. As the relative energy-cost increases, it induces firms to reallocate and selectively utilize the most energy-efficient vintages. In the long-run firms could also achieve energy efficiency through investments in energy-efficient capital. This study uses the Canadian KLEMS panel data set to investigate these relationships. We employ panel vector auto regressions as well as co-integration and error correction techniques to test whether the conjectures hold in the data. Our findings support the theoretical conjectures. The channels we empirically identify suggest that the effect of increased energy-cost can be an increase in energy efficiency: by decreasing energy-capital ratio and increasing output-capital ratio. The latter effect is observed only in the long-run through induced investments in new capital.

JEL classification codes: Q41, Q43, Q48, C33
Key Words: Energy intensities, Capital productivity, Energy Price, Panel Data

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‡For replication, the codes and data in this paper are available on request.

1 Introduction

There is an increased pressure on policy makers to adopt carbon tax policies in order address the problem of global warming. This policy can be controversial because it increases energy-cost of production. Economic theories assert that a rise in energy cost contributes to economic slowdown through its impacts on capital utilization in the short-run – by inducing firms to reallocate and selectively utilize the most energy-efficient ones among the existing vintages. That means, as the relative energy-cost increases, firms are induced to reallocate their input utilization. In the long-run, firms could also invest in energy-efficient capital. Both of these channels, capital utilization and investment in efficient capital, have implications for capital productivity and energy efficiency. The reduction in energy-capital ratio, either through adjustments in capital utilization or investment in efficient capital, would lead to a lower energy-output ratio – an energy efficiency improvement. Since the reduction in energy-output ratio can be partly attributed to investments in energy-efficient capital, a lower energy-output ratio is not only achieved through the reduction in the energy-capital ratio caused by capital reallocation.

More clearly, a rise in energy price (energy-cost) implies lower energy-capital and energy-output ratios both in the short- and the long-runs. The short- and long-run effects induced by energy price shocks have implications for the output-capital ratio (capital productivity). The short-run effect, utilizing the most energy-efficient capital, can reduce the services flowing from the overall capital stock, potentially reducing the productivity of the existing capital stock. Thus, the induced improvement in energy efficiency of capital may be because of retrenchment of some old capital vintages. On the other hand, the long-run effect – induced investment in new energy efficient capital – can improve capital productivity. To elucidate these intricacies, this paper studies how the three variables (energy-capital, output-capital, and energy-output ratios) are affected by energy price, controlling for the other input prices.

Some of these insights are gleaned from the literature explaining the economic effects of energy price has been a subject of several studies because energy price shocks cause far more effects than could be explained by energy's share in the production cost (Rotemberg and Woodford (1996), Atkeson and Kehoe (1999), Finn (2000), Hamilton (1983), Hamilton (1996), Hamilton (2010)). The observed effects are far larger than could be explained by considering energy as one of the inputs in aggregate production because of the small cost share of oil in production (Kilian, 2008). Various explanations have been proposed for such a larger effect of energy cost. Jorgenson (1981) and Hall (1988) argued that the mechanism by which energy price slows down economic activity is by slowing down productivity growth. Dhawan et al. (2010) argue that the recessions in the 1970s and 1980s occurred not because of the direct effect of the energy price hikes during the oil crisis but because of their spill-over effect on the productivity of other inputs.

The question of how productivity effects are engendered was tackled by Berndt and Wood (1984), Berndt and Fuss (1986), and Berndt et al. (1991). For them, part of the changes in total factor productivity is due to changes in capital utilization which are negatively affected by the energy price. The change in capital utilization occurs because a rise in energy cost induces firms to selectively utilize the most energy efficient ones from among the existing equipment and machinery. Baily et al. (1981) also contended that a fall in capital services is the key to understanding the effect of energy price on the economy. Wei (2003) shows that the probability that existing capital stock is utilized depends on whether the resulting value added is greater than the variable input costs; namely energy and labor costs. Therefore, higher energy price (and labor cost) makes utilization of energy-inefficient capital less likely, thereby reducing energy intensity (energy used per capital) of existing capital in the short run. Finn (2000) discusses this relationship by using a specific functional relationship between capital utilization and energy intensity of capital. These propositions together suggest the existence of a negative relationship between energy price and energy intensity of capital because of the utilization effect.

A little differently, Atkeson and Kehoe (1999) explain how the long- and the short-run price effects are different using the putty-clay framework which assumes that energy intensity of capital is chosen at the beginning of investment.[1] That is, firms can choose high or low energy intensity ex-ante, but ex-post it is fixed. Then, firms have little options in terms of changing their energy demand. Therefore, the capital utilization rate is the only mechanism that can influence energy intensity in the short-run. In the long-run, however, firms could replace old capital with new, energy efficient ones. In both ways, energy-intensity of capital (energy-capital ratio) is negatively related to energy price, all else remaining the same – this is one of the two tests we empirically analyze. We further test the effect of energy-capital ratio on the energy-output ratio as one of the mechanisms of achieving energy efficiency.

[1] The putty-clay framework is consistent with empirical findings that energy and capital are complementary in the short-run but substitutes in the long-run. The long-run substitutability between capital and energy in this framework is a result of newer capital requiring less energy. That is, substitution between energy and capital is not in literal sense that more capital is utilized instead of energy but rather due to the fact that capital with lower energy intensity replaces older capital.

There are also other strands of economic theories that assert that energy efficiency improvements arise from investments in new capital induced by rising energy costs (see Acemoglu et al. (2012), Perez-Barahona and Zou (2006), and Boucekkine and Pommeret (2004)). Numerous empirical studies provide evidence that firms and people adopt energy efficient equipment and capital in response to higher energy costs (e.g. Linn (2008), Newell et al. (1999), Doms and Dune (1995),and Boyd and Karlson (1993)). This effect from the induced new investment takes place in the long-run (Hogan (1989), Newell et al. (1999), and Newell et al. (1999)). This may imply improvements in output productivity of capital as per the capital-embodied technical progress theory, which posits that investments in newer and more efficient capital can lead to improvements in overall productivity (Solow (1960), Solow (1962), and Benhabib and Rustchini (1991)). We analyze whether energy price increases capital productivity (output-capital ratio) which in turn decreases energy intensity of output (energy-output ratio) – this is our second empirical test.

The objective of this paper is to empirically identify the short- and long-run mechanisms through which energy cost increases the energy efficiency of output. There are two theoretical channels we test: first, a rise in energy price leads to a fall in the energy-capital ratio which in turn decreases energy-output ratio. Second, a rise in energy price leads to a rise in the output-capital ratio (capital productivity) which leads to a decrease in energy-output ratio. The insights from the existing literature suggest that first, it is important to identify the short- and long-run empirical relationships between energy-capital ratio and energy price. Whether output-capital ratio is positively affected by energy price in the long-run is a crucial question to identify whether the induced investment hypothesis is taking place. As shown in the next section, by definition, the elasticity of energy-output ratio with respect to energy price is equal to the sum of the elasticity of energy-capital and output-capital ratios with respect to energy price. Since the induced investment mechanism occurs only in the long-run, this relationship suggests that the elasticity of energy-capital and energy-output ratios with respect to energy price are equal in the short-run. Indeed, we find this result from our estimations.

We first estimate two sets of panel vector autoregressions (PVAR) to show the general relationships. In the first, we see the effect of an orthogonal shock to energy price on energy-capital ratio and energy output ratio. In the second one, we see the effect of an orthogonal shock to energy price on output-capital ratio and energy-output ratio. We then apply panel co-integration and error-correction techniques to identify the short- and long-run elasticity of energy-capital ratio (energy intensity of capital), output-capital ratio (capital productivity), and the energy-output ratio (energy intensity of output) using the Canadian KLEMS data set.[2] These data cover the entire business sector of the economy, identified according to the North American Industry Classification System (NAICS), to 4 digit disaggregation. It includes 33 industries, excluding the services sectors such as health, education, and transportation. Thus, our focus is on the sectors that produce goods and those that support the production activities in the Canadian economy. Our annual data spans the 1961 - 2007 period. We use panel unit root and co-integration tests, and estimate the long-run and short-run coefficients using panel error correction methods developed by Gengenbach et al. (2009), Hlouskova and Wagner (2006), Pesaran and Smith (1995), Im et al. (2003). These methods

[2]KLEMS stands for capital, labor, energy, materials, and services, respectively.

are particularly convenient to simultaneously estimate and present both the short-run and long-run coefficients while also testing whether there is a long-run co-integrating relation.

We find statistically significant relationships between energy price and all the three variables studied. In the first PVAR, in response to unexpected energy price shock, both energy-capital ratio, and energy-output ratio decrease. In the second PVAR, in response to energy price shock, the output-capital ratio increases, and energy-output ratio decreases. From panel co-integration and error correction model, the long-run elasticity of energy intensity of capital with respect to energy price is -0.23 while that of the energy-output ratio is -0.41. The long-run elasticity of capital productivity with respect to energy price is 0.1. The short-run elasticities of energy-capital and energy-output ratios are almost equal (-0.23 and -0.24, respectively). All these results are as hypothesized by the theoretical relationships. However, these suggest that a short-run decrease in energy intensity of output is not an efficiency improvement in its strict sense; that is, it does not imply maintaining the same level of production while reducing energy utilization. Another interesting result is that the long-run and short-run elasticities of energy intensity of capital are identical. On the other hand, we do not find a statistically significant short-run relationship between energy price and capital productivity in the error-correction model, again consistently with the theoretical conjectures. Together the results imply that adjustment in capital utilization is the channel through which energy price affects energy intensity of the economy in the short-run while induced investments play additional roles in the long-run. Another interesting result is that the difference between the long-run and the short-run elasticity of energy-output ratio with respect to energy price is equal to the long-run elasticity of capital productivity, suggesting that induced investments in new capital contributes to improvements in capital productivity and thereby, to improvements in energy productivity in the long-run.

The effect of carbon tax policy is similar (the same) to increase in energy cost. Then, the policy implication is that a rise in energy cost that is expected when a carbon tax is levied may have a negative economic effect in the short-run through induced reduction in capital utilization. In the long-run, however, capital productivity can be improved through induced investments in new capital, thereby contributing to the overall productivity.

The paper is organized as follows. Section 2 presents a very brief note on the conceptual frameworks. Model specification and estimation methods are discussed in section 3 followed by a description of data and presentation of the estimation results in section 4. Section 5 presents concluding remarks.

2 Conceptual Frameworks

As standard, output is determined using capital services and labor, augmented by factor productivity which indexes technology. Capital services are the product of physical capital and capital utilization. Following Finn (2000) we denote production function as $y_t = F(u_t k_t, z_t)$ where y_t is output-labour ratio, u_t is capital utilization, k_t is capital-labour ratio and z_t is labour-augmenting productivity. Capital utilization is a function of energy-intensity of capital ($u_t = f(e_t/k_t)$). Accordingly, an exogenous increase in energy price reduces optimal quantity of energy used in production, thereby reducing the $\frac{e}{k}$ ratio (valid for the short-run situation when k is constant), thereby reducing capital utilization. Since this reduces ouptutlabour ratio, it must imply a lower output-capital ratio (worsening of capital productivity).

When capturing the negative effects of energy price through its effects on the energy intensity of capital, thereby on capital utilization, one should not, however, forget that capital productivity is potentially affected positively in the long-run through investments in new vintages. The putty-clay framework captures both the short-run utilization and the long-run investment effects of energy prices. In the putty-clay framework proposed by Atkeson and Kehoe (1999) and also discussed in Wei (2003), utilization decision for existing capital stock is carried out for each existing vintage at one point in time for a long period of time. Specifically, Wei (2003) shows that the probability of using a specific capital equipment of certain vintage depends on the probability that the per-labour value added from the capital's operation is larger than the operation costs, which comprises labour and energy costs.[3]

Using the dual production technology, cost function, and assuming that a representative firm minimizes cost, we can show that energy intensity of capital is also affected by the prices of other inputs. That is, suppose a cost function, assuming constant returns to scale, is given as

$$C = YC(P_1, P_2, ..., P_n, Y; A^{-1}) \tag{1}$$

where Y is output, P_i are the input prices, and A is the index of technical progress. Then,

[3] Assuming a mean-reverting log-normal distribution for productivity coefficient for specific vintage and capital equipment, this benchmark rule generates a cumulative density function in which labour productivity and prices of the variable inputs are the arguments. This function governing utilization of capital can then be linked to energy-intensity of capital using the relationship given above. In other words, assuming capital-energy complementarity suggests that increased utilization of capital requires more energy being used per unit of capital.

using Shepard lemma, the optimal demand for an input is given as

$$X_i = \frac{Y\partial C(P_1, P_2, ..., P_n; A^{-1})}{\partial P_i} \tag{2}$$

so that

$$\frac{X_i}{Y} = f(P_1, P_2..., P_n; A^{-1}) \tag{3}$$

where f denotes the functional relationship. If the inputs indexed by i consist of capital (K), Labour (L), energy (E), and Materials (M), equation 3 provides a conceptual underpinning for modeling factor productivity of the inputs as functions of the input prices and technical progress. Equation 3 can be used for modeling energy intensity of the economy ($\frac{E}{Y}$) and capital productivity $\left(\frac{1}{K/Y} = Y/K\right)$ as functions of all factor prices and the technology. Furthermore, the ratio of any two of the inputs, $\left(\frac{X_i/Y}{X_j/Y} = \frac{X_i}{X_j}\right)$, is also dependent on the arguments in the function $f(.)$. Thus, the energy-intensity of capital $\left(E/K = \frac{E/Y}{K/Y}\right)$ is also a function of all input prices.

It can be shown that the elasticity of energy-output ratio with respect to energy price is equal to the price elasticity of energy-capital ratio minus that of capital productivity. That is, given the identity

$$\frac{E}{K} = \frac{E}{Y} \times \frac{Y}{K}, \tag{4}$$

the elasticity with respect to energy price, all else remaining constant, is given as

$$\frac{\partial ln(E/K)}{\partial ln P_E} = \frac{\partial ln(E/Y)}{\partial ln P_E} + \frac{\partial ln(Y/K)}{\partial ln P_E} \tag{5}$$

This can be written as:

$$\frac{\partial ln(E/Y)}{\partial lnP_E} = \frac{\partial ln(E/K)}{\partial lnP_E} - \frac{\partial ln(Y/K)}{\partial lnP_E} \tag{6}$$

Equation 6 can imply the mechanisms by which a rise in energy price results in improvements in energy efficiency – through reduction in energy-intensity of capital and improvements in productivity of capital that are driven by both utilization adjustments and new investments induced by the increased energy costs. Given that the elasticity of output-capital ratio with respect to energy price is positive while that of energy-capital ratio is negative, the equation says that the elasticity of energy-output ratio with respect to energy price is the sum of the two elasticities.

3 Model Specification

3.1 Panel vector autoregression specification

Following the recent development by Abrigo et al. (2015) our specification of a p order panel vector regression is given as

$$Y_{it} = Y_{it-1}A_1 + Y_{it-2}A_2 + Y_{it-3}A_3 ... + Y_{it-p}A_p + u_{it} + e_{it} \tag{7}$$

where $i \in 1, 2, 3...N$ denotes our sectors, and $t \in 1, 2, ...T_i$ denotes years, Y_{it} denotes $(1 \times k)$ vector of dependent variables, u_{it} and e_{it} are $(1 \times k)$ vectors of panel-specific fixed effects and idiosyncratic errors, respectively. We first estimate $(k \times k)$ matrices $A_1, A_2, A_3 ... A_p$. We assume $E(e_{it}) = 0$, $E(e'_{it} e_{it}) = \Sigma$ and $E(e_{it} e_{is}) = 0$ for all $t > s$. We do not include exogenous variables. We estimate two regressions in our vector auto regressions. In the first regressions Y is the first difference of the natural logarithm of energy price, energy-capital ratio, and energy-output ratio, respectively. In our second regressions, Y is the first difference of the natural logarithm of energy price, output-capital ratio, and energy-output ratio, respectively. In both cases, we estimate the variables in their respective order. Our interest is to see the orthogonalized impulse responses of the variables to energy price shock.

We estimate our panel vector autoregressions in generalized method of moments style (GMM) because it is efficient. To briefly indicate our impulse responses, let's denote the A_i matrices in 7 as:

$$\bar{A} = \begin{bmatrix} A_1 & A_2 & ... & A_p & A_{p-1} \\ I_k & 0_k & ... & 0_k & 0_k \\ 0_k & 0_k & ... & 0_k & 0_k \\ \vdots & \vdots & \ddots & \vdots & \ddots \\ 0_k & 0_k & ... & 0_k & 0_k \end{bmatrix}$$

Our var is stable if all moduli of $\bar{A}$ is strictly less than one.[4] Then we can invert $\bar{A}$ and represent 7 in an infinite moving-average with parameter vector Φ_i such that

$$\Phi = \sum_{j=1}^{i} \Phi_{t-j} A_j, \text{where } i = 1, 2, ... \tag{8}$$

We stress the ordering of dependent variable so that the Cholesky decomposition gives us a causal meaning in orthogonalized impulse-responses. That means, in both regressions,

[4]For details, please, see Abrigo et al. (2015).

energy-price, the first element causes the second element, and the first and second elements cause the third element. Simply, we are following the theoretical identification we discussed in section 1. We are just interested in the directions of changes of our variables after energy price shock.

3.2 Co-integration and error correction model specification

The co-integrating regression for the panel of the goods producing industries is specified as

$$Y_{it} = \beta_i' X_{it} + \alpha_i + \alpha_{it} t + \epsilon_{it}, \tag{9}$$

the dependent variable Y_{it} is a vector of natural logarithm of energy-capital, energy-output, and capital-output ratios and X_{it} it is a vector containing natural logarithms of the input prices; α_i is the member-specific intercept, and the term $\alpha_i t$ captures the member-specific time-effect; ϵ_{it} is the error term. The parameters of the co-integrating regression represent long-run effects. The goal is to identify both short-run and long-run elasticity effects. To this effect, a more general dynamic specification (auto-regressive distributive lag $(ARDL(p, q))$ is adopted:

$$Y_{it} = \sum_{j=1}^{p_i} \lambda_{ij} Y_{i,t-j} + \sum_{j=0}^{q_i} \beta_{ij}' X_{i,t-j} + \alpha_i + \alpha_{it} t + \epsilon_{it}, \tag{10}$$

with the lag-lengths selected based on certain information criteria such as the Akaike or Bayesian information criterion. The time period, T, must be large enough to permit estimation for each group separately.

3.2.1 The panel unit root test

There are a number of methods proposed to carry out panel unit root tests (see Gengenbach et al. (2009) and Hlouskova and Wagner (2006) for reviews).[5] The Im et al. (2003) test that permits heterogeneity of the auto-regressive parameter relies on a restrictive assumption that the individual time series in the panel are cross-sectionally independently distributed. Pesaran (2007), on the other hand, proposed a unit root test method that accounts for both cross-sectional correlations and heterogeneous coefficients. He uses a simple dynamic heterogeneous model given as:

$$Y_{it} = (1 - \phi_i)\mu_i + \phi_i Y_{i,t-1} + u_{it} \tag{11}$$

and assuming that u_{it} has the single-factor structure:

$$u_{it} = \gamma_i f_t + \epsilon_{it} \tag{12}$$

where f_t is the unobserved common effect and ϵ_{it} is individual-specific error so that equation 12 can be written as

$$Y_{it} = (1 - \phi_i)\mu_i + \phi_i Y_{i,t-1} + \gamma_i f_t + \epsilon_{it} \tag{13}$$

[5]The Levin et al. (2002) and Harris and Tzavalis (1999) tests make the simplifying assumption that all panels share the same auto-regressive parameter, making them less preferred methods.

and the unit root hypothesis of interest in equation is $\phi_i = 1$ for all i. A more convenient way to proceed is to express equation 13

$$\Delta Y_{it} = \alpha_i + \beta_i Y_{i,t-1} + \gamma_i f_t + \epsilon_{it} \tag{14}$$

where $\alpha_{it} = (1-\phi_i)\mu_i$; $\beta_i = -(1-\phi_i)$ and $\Delta Y_{it} = Y_i - Y_{i,t-1}$ and the unit root test of interest is now $\beta_i = 0$ for all i.

The alternative hypotheses are heterogeneity across the panels; that is, $H_A: \ \beta_i < 0$ for some cross-section units and $\beta_i = 0$ for the rest of the panels. That is, the alternative hypothesis is formulated such that at least some panels are non-stationary. Pesaran uses the cross-sectional average $\bar{Y}_t = \frac{1}{N}\sum_{i=1}^{N} Y_{i,t}$ and its lags $\bar{Y}_{t-1}$, $\bar{Y}_{t-2}$... as a proxy for the common factor f_t. He then proposed a test based on the t-ratio of the OLS estimate of $\hat{b}_i$ in

$$\Delta Y_{it} = \alpha_i + b_i Y_{i,t-1} + c_i \bar{Y}_{t-1} + d_i \bar{Y}_t + e_{it} \tag{15}$$

If u_{it} in equation 11 is serially correlated, equation 15 would be specified as

$$\Delta Y_{it} = \alpha_i + b_i Y_{i,t-1} + c_i \bar{Y}_{t-1} + \sum_{j=0}^{p} d_{ij} \bar{Y}_{t-j} + \sum_{j=1}^{p} \delta_{ij} \Delta Y_{i,t-j} + e_{it} \tag{16}$$

The panel unit root test is then, based on the simple average of the individual Augmented Dickey-Fuller (ADF) tests based on equation 16. Here, we note that the method is similar to that of Im et al. (2003) in which cross-sectional dependence is handled differently; namely by demeaning (deducting the overall averages) the variables. The test is conducted under the null hypothesis that the series is integrated of order one, I(1). Thus, non-rejection of the null implies that we believe the series as an I(1) process. The deterministic term (α_i) can either include constant or both constant and the time trend. The test statistic for both Pesaran (2007) and Im et al. (2003) is given as

$$t - bar = \frac{1}{N} \sum t_{pi} \tag{17}$$

where t_{pi} is the ADF test statistic computed under $H_0 : \; b_i = 0$, where the subscript pi indicates that each panel is allowed to have its own lag structure.

3.2.2 Panel co-integration and error-correction tests

The error-correction based methods are attractive given that they enable us to check the existence of co-integration tests through tests that ascertain the existence of error-corrections while – permitting estimation of long-run and short-run parameters.

The error-correction-based panel co-integration tests are implemented by testing the null hypothesis of no co-integration by inferring whether the error-correction term in a conditional panel error-correction model is equal to zero (Pesaran and Smith (1995) and Pesaran et al. (1999)). The error correction method based on the following data generating process derived from equation 10:

$$\begin{aligned} \Delta Y_{it} = \phi_i(Y_{i,t-1} - \theta_i^{'} X_{i,t-1}) + \sum_{j=1}^{p_i-1} \lambda_{ij}^{*} \Delta Y_{i,t-j} + \\ \sum_{j=1}^{q_i-1} \beta_{ij}^{'*} \Delta X_{i,t-j} + \alpha_i + \alpha_{it} t + \epsilon_{it} \end{aligned} \tag{18}$$

where $\phi_i = -(1 - \sum_{j=1}^{p} \lambda_{ij})$; $\theta_i = \sum_{j=0}^{q} \delta_{ij}/(1 - \sum_k \lambda_{ik})$; $\lambda_{ij}^* = -\sum_{m=j+1}^{p} \lambda_{im},\ j = 1, 2, ..., p-1$; and $\beta_{ij}^* = \sum_{m=j+1}^{q} \beta_{im},\ j = 1, 2, ..., q_1 - 1$. The parameter ϕ_i determines the speed at which the system corrects back to the equilibrium relationship $Y_{i,t-1} - \theta_i' X_{i,t-1}$ after a sudden shock.

If $\phi_i < 0$, then there is error correction, implying that Y_{it} and X_{it} are co-integrated. On the other hand, if $\phi_i = 0$, there is no error correction and, therefore, no co-integration. Thus, the null hypothesis of no co-integration can be stated as $H_o : \phi_i = 0$ for all i.

Pesaran and Smith (1995) assume that the parameters are different across the individual groups and proposed a method of estimating the groups separately and then averaging the coefficients, known as the mean group (MG) approach. Then, the test is performed for $\hat{\phi} = \frac{1}{N} \sum_{i=1}^{N} \hat{\phi}_i$, computed with the variance $\frac{1}{N(N-1)} \sum_{i=1}^{N} (\hat{\phi}_i - \bar{\hat{\phi}})^2$. The mean and variance of other parameters are computed the same way. Alternatively, Pesaran et al. (1999) proposed a method based on a combination of pooling and averaging in which the intercepts, the short-run coefficients, and error variances differ across groups but the long-run coefficients are constrained to be equal across groups (PMG). A maximum likelihood estimation method is proposed given the non-linearity of equation 18, wherein the log-likelihood function that needs to be maximized is obtained as a product of the log-likelihood functions of each of the individual groups.[6] This pooling across the individual units yields efficient and consistent estimates when the restrictions are true. However, if the true model is heterogeneous, the PMG is inconsistent whereas the MG is consistent in either case. Selection between these two approaches requires a formal testing using the Hausman test.

[6] Stata's xtpmg command due to Bluckbrune and Frank (2007) employs the algorithm which begins with 0 initial estimates of the long-run coefficient vector β_i . The short-run coefficients and the group-specific speed of adjustment terms are then estimated given β_i, with iterations continuing until convergence is achieved.

4 Empirical Analysis

4.1 Data

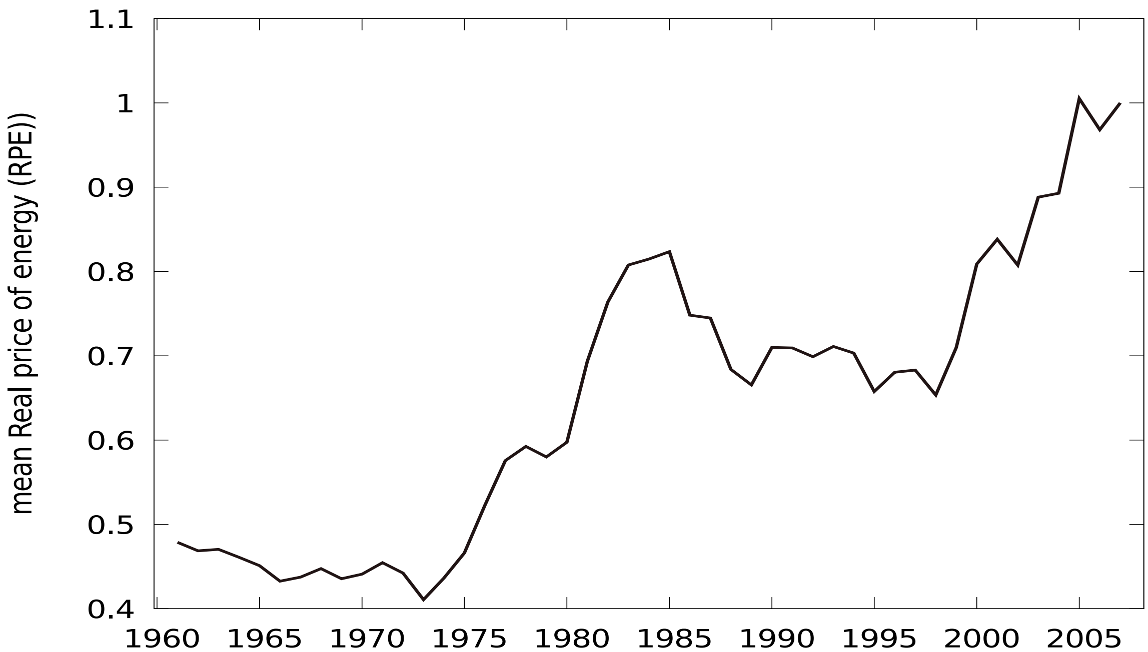
The Statistics Canada's KLEMS (Capital - Labour - Energy-Materials-Services) data set provides input, output, prices, and productivity indices for Canadian industries for the period 1961-2007. We focus on the goods producing sectors, excluding service sectors such as the education and health sectors. We analyze the data of industries listed in table 1.

Table 1: Goods Producing Industries(NAICS)

1	Crop and Animal Production[11A0]	17	Clothing, Leather and Allied Product[315 - 316]
2	Forestry and Logging[1130]	18	Wood product [3210]
3	Fishing, Hunting, and Trapping [1140]	19	Pulp, paper and paperboard Mills [3221]
4	Support Activities for Ag. and Forestry[1150]	20	Printing and related [3231]
5	Oil and Gas Extraction [2111]	21	Petroleum and coal [3241]
6	Coal Mining [2121]	22	Chemical [3250]
7	Metal Ore Mining[2122]	23	Plastic Product [3261]
8	Non-Metallic Mining and Quarrying[2123]	24	Rubber Product [3262]
9	Support activities for Min. and Oil and Gas ext.[2131]	25	Non-metallic Mineral Product [3270]
10	Electric Power Generation, Transmission and Distribution [2211]	26	Primary Metal [3310]
11	Natural Gas Distribution, [221A] Water, Sewage and Other Systems	27	Fabricated Metal [3320]
12	Construction [2300]	28	Machinery [3330]
13	Food Manufacturing [3110]	29	Computer and Electronic Product[3340]
14	Beverage Manufacturing [3121]	30	Electrical Equipment, Appliance and Components [3350]
15	Tobacco [3122]	31	Transportation Equipment [3360]
16	Textile and Textile Product [31A0]	32	Furniture and Related [3370]
		33	Miscellaneous Manufacturing [3390]

Figure 1 shows trends in average real energy price across the sectors. A simple average is calculated after dividing energy prices by output price indexes in each sector for each year. In the figure, real energy price steadily increased during the period between 1974 and the mid-1980s, showing the effects of the international oil crisis of the era.

Figure 1: Trends in the Average Real Energy Prices

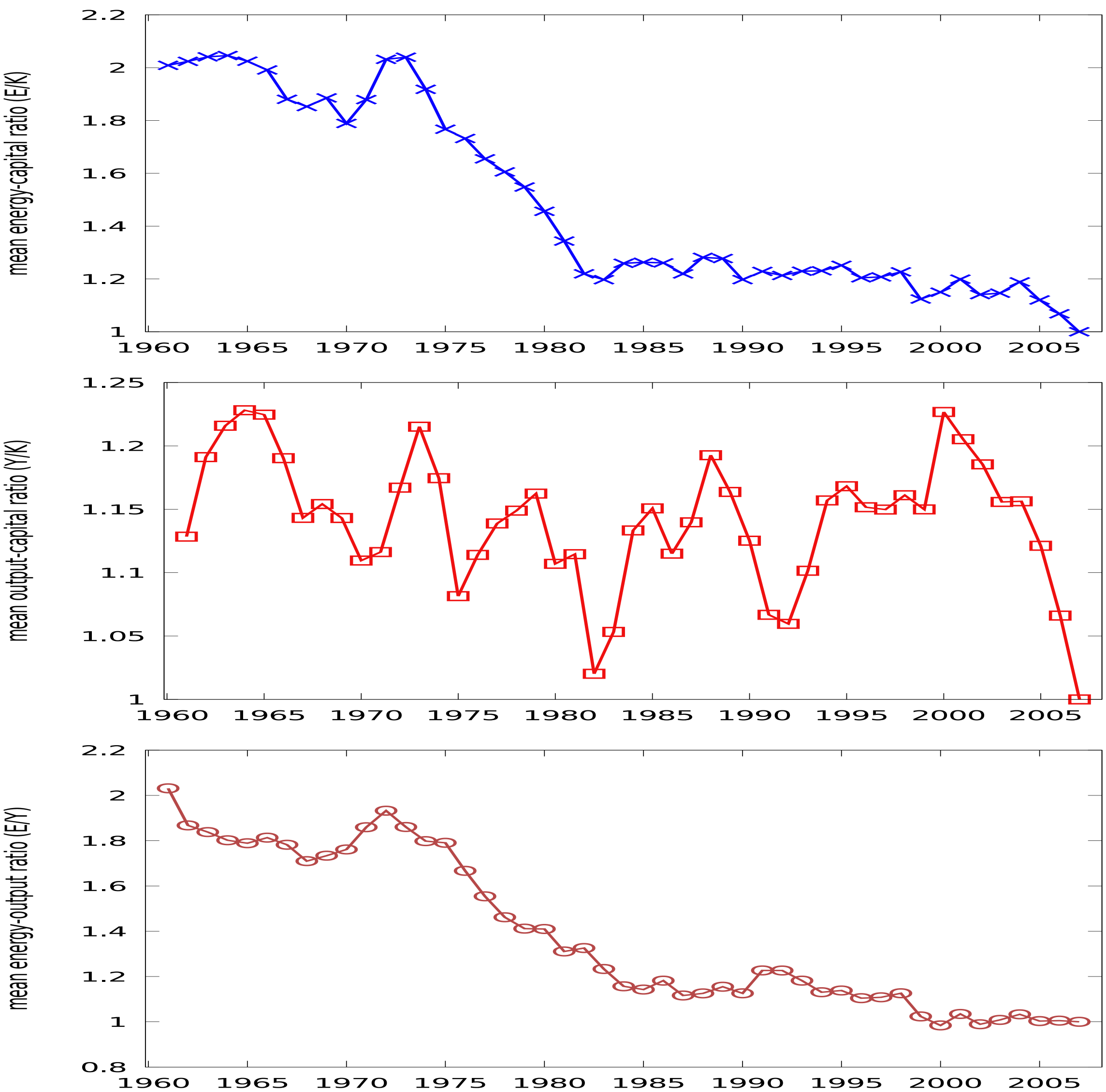


The trends of the three variables: energy-capital, output-capital, and energy-output ratios are shown in figure 2. We observe that the energy-capital ratio decreases concurrently with the rise in real energy price. This suggests the existence of strong short-run response that likely signify the role of capital utilization effects. No clear pattern is observed in the capital productivity (output-capital ratio). Energy efficiency of production (energy-output ratio) has clearly decreased while the real energy price is increasing.

In table 2, the average growth rates in the three variables along with the rate of changes in real energy price are averaged over spans of years that appear to mimic the breaks in the energy price trends, visually.

According to 2, during the periods of increase in average growth rates in real energy

Figure 2: Trends in Energy-Capital, Output-Capital and Energy-Output Ratios



price (Δln(RPE)), energy intensity of capital (Δln(E/K)) decrease. For example, the average growth rate in real energy prices during the period 1974-1983 was approximately eight percent. During the same period, energy intensity of capital decreased by an average of four percent. Similarly, during the period 2001-2007, the average price of real energy price increased by roughly four percent. During the same period,the average growth rate in energy intensity of capital decreased by approximately 1.5 percent. Other periods follow a similar trend.

Table 2: Average growth rates

Variable	1962 -1973	1974 - 1983	1984 - 1992	1993 - 2000	2001 - 2007
Δln(RPE)	-0.004	0.078	-0.013	0.020	0.041
Δln(E/K)	0.005	-0.039	0.009	-0.005	-0.015
Δln(Y/K)	0.006	-0.009	0.005	0.018	-0.024
Δln(E/Y)	-0.002	-0.030	0.004	-0.023	0.010

Table 2 also shows that the growth rates of real energy prices (ΔlnRPE) and capital productivity (Δln(Y/K)) follow an opposite sign except for the period 1993-2000. The magnitudes of the changes in capital productivity is small for the periods 1962-1992. In the period 1993-2000, average real energy price increased by two percent while capital productivity increased by 1.8 percent. In contrast, during the period 2001-2007, average real energy price increased by roughly four percent while capital productivity decreased by 2.4 percent. Therefore, we do not observe a conclusive relationship between real energy price and capital productivity from the rough averaging of the growth rates

The relationship between the real energy price and energy intensity of output (Δln(E/Y)) is interesting. During the period 1962-1973, the magnitude of growth rates in both variables is negligible. During the sharp increase in real energy price between 1974-1983 is when the the energy intensity of output also decreased the most. Between 1993-2000 and 2001-2007, real energy price increased by two and 4.1 percent, respectively. In contrast, during the same period, energy intensity of output decreased by 2.3 and one percent, respectively. Roughly, we see a negative relationship between the two variables as the theories predict.

Table 3 provides the overall correlations of the three variables, energy efficiency of capital,

capital productivity, and energy efficiency of the output. The correlations are consistent with the theoretical predictions: 1) real energy price is negatively correlated with the energy intensity of capital; 2) real energy price is positively correlated with capital productivity; 3) real energy price is negatively correlated with the energy intensity of output.

Table 3: Overall Correlations

	ln(E/K)	ln(Y/K)	ln(E/Y)	lnRPE
ln(E/K)	1			
ln(Y/K)	0.43***	1		
	(0.00)			
ln(E/Y)	0.75***	-0.27***	1	
	(0.00)	(0.00)		
lnRPE	-0.23***	0.17***	-0.38***	1
	(0.00)	(0.00)	(0.00)	

We further explored whether these correlations hold consistently across individual firms. We found several exceptions though the results generally hold. In Appendix 5 tables 7 we present industry-specific correlations between real energy price and the three variables. In Panel A we find a statistically significant negative correlation between energy price and the E/K ratio in most of the industries. In particular, statistically significant positive correlations were observed in three industries and no statistically significant correlation exists in 5 industries. In panel B, we find a statistically significant positive correlation between real energy price and the Y/K ratio in most industries. However, nine of the industries have a negative correlation in this dataset. Statistically significant positive correlations are observed in less than 50% of the cases. In Panel C, we report the mostly negative correlation between the real energy price and the E/Y ratio. Only two of the industries have a positive and significant correlation while the correlations are not statistically significant in four industries. In general, we find the correlation between the real energy price and E/K, the real energy price and Y/K, the real energy price and E/Y are negative, positive, and negative, respectively; as the theory we test suggests.

Figures 3, 4, and 5 present the scatter plots of the three variables on vertical lines versus real energy price on horizontal lines. The ordinary least square fits of the scatter points show a consistent result with the correlations presented above. More information for industry-specific correlations is provided in appendix tables.

Figure 3: Energy-capital ratio and real energy price

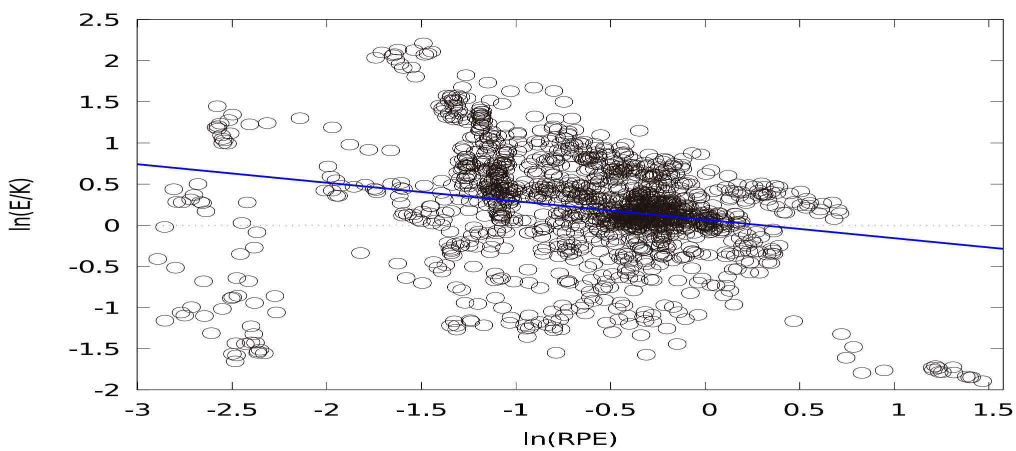


Figure 4: Output-capital ratio and real energy price

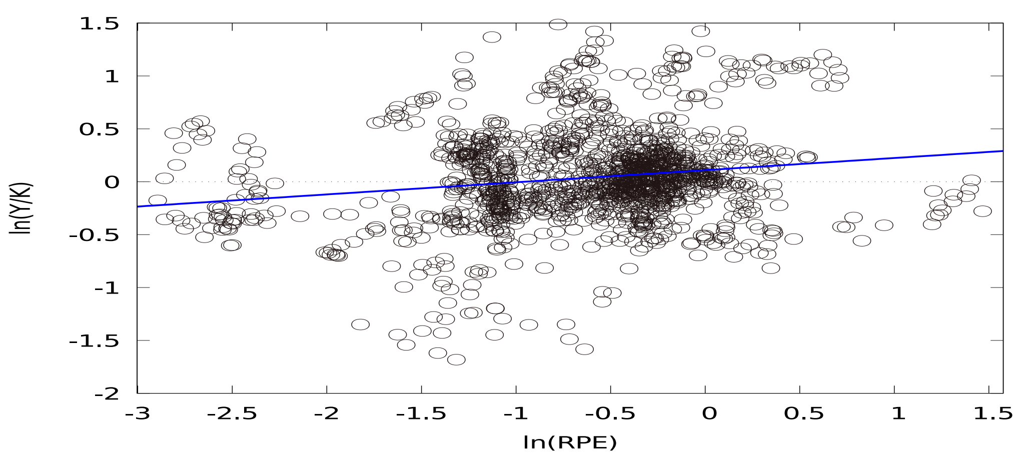
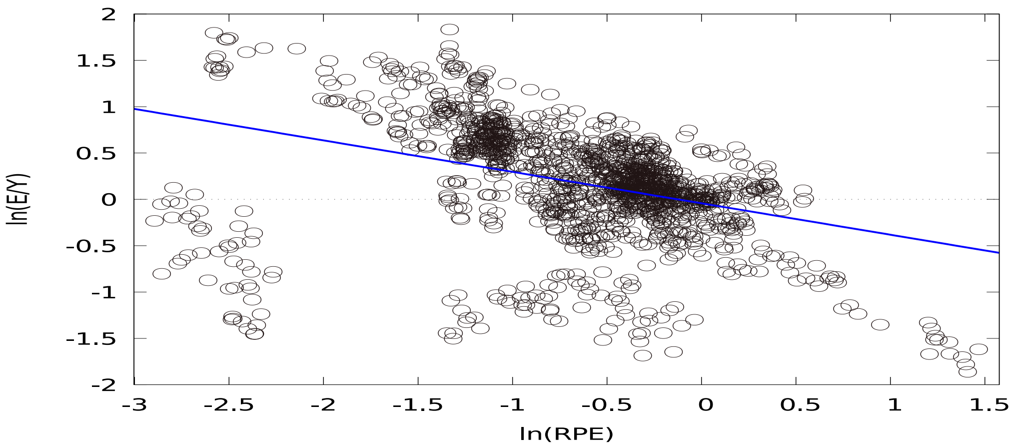


Figure 5: Energy-output ratio and real energy price



Generally, from the preliminary analysis of this section, we find that a negative correlation between real energy price and energy intensity of capital (positive correlation between real energy price and capital efficiency (K/E)). We find a strong positive correlation between energy efficiency (negative in terms of E/Y – energy intensity of output) and real energy prices. The correlation of output-capital ratio to the real price of energy had more exceptions than the other two variables. However, it the correlation is positive in most of the industries. This suggests that the possibility of improvements in energy efficiency of capital translating to improvements in capital productivity can depend on the nature of the specific industries.

Table 4 presents the summary statistics of the variables we use in estimations.

4.2 Results

4.2.1 Non-Stationarity

Unit root test results based on Pesaran (2007) and Im et al. (2003) methods are presented in table 5. The results of both tests as well as the others not reported here confirm non-

Table 4: Overall Correlations

Variable Name	Notations	Mean	Minimum	Maximum	St.Deviation
Real energy price	$ln(RPE)$	-0.61	-2.89	1.47	0.65
Energy intensity of capital	$ln(E/K)$	0.21	-1.89	2.21	0.62
Capital productivity	$ln(Y/K)$	0.04	-1.68	1.49	0.42
Energy intensity of output	$ln(E/Y)$	0.17	-1.86	1.83	0.58
Capital price	$ln(RPK)$	-0.04	-3.24	1.31	0.55
Labour price	$ln(RPL)$	-0.23	-2.27	1.52	0.46
Materials prices	$ln(RPM)$	0.71	-0.23	7.18	1.23
Services prices	$ln(RPS)$	-0.37	-1.60	1.23	0.42

Notes: All variables are in natural logarithms; R in the price notations indicate that all were presented in real terms. There are 33 industries and 47 years in the panel data. The inverse of the ratios E/K and E/Y (K/E and Y/E) can also be interpreted as energy efficiency of capital and energy productivity, respectively.

stationarity of the series, suggesting that long-run relationships have to be established based on co-integration tests. The results show that all variables are integrated of order one ($I(1)$).[7]

Table 5: Pesaran (2007) and Im et al. (2003) Unit Root Tests: H0 : Panels are I(1).

		$ln(RPE)$	$ln(E/K)$	$ln(Y/K)$	$ln(Y/E)$	$ln(RPK)$	$ln(RPL)$	$ln(RPM)$
In Level								
Pesaran (2007)	t-bar	-1.27	-2.51	-2.10	-2.28	-2.57	-1.98	-1.61
	p-value	1.00	0.14	0.94	0.66	0.07	0.99	1.00
Im et al. (2003)	t-bar	1.69	-0.35	0.45	-1.10	-0.59	0.47	12.59
	p-value	0.95	0.36	0.67	0.13	0.28	0.68	1.00
In first difference								
Pesaran (2007)	t-bar	-3.37	-3.64	-3.36	-4.05	-4.17	-3.62	-3.42
	p-value	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Im et al. (2003)	t-bar	-21.44	-30.29	-25.85	-33.05	-23.67	-29.69	-12.77
	p-value	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Notes: All variables are in natural logarithms; R in the price notations indicate that all were presented in real terms. There are 33 industries and 47 years in the panel data.

[7] We have also used the (Levin et al., 2002) method for unit root test; the result indicate the same result.

4.2.2 Panel vector autoregression results

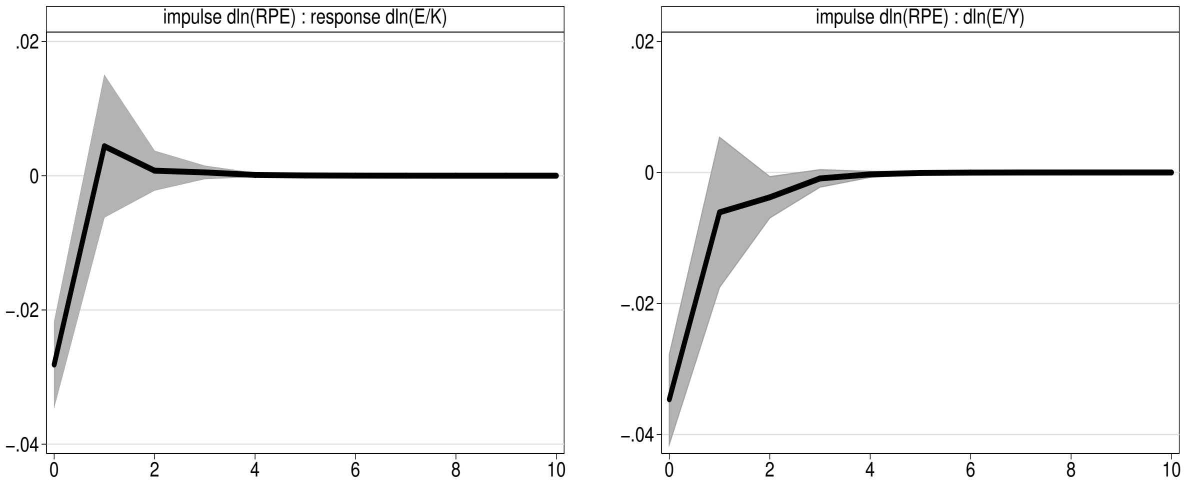
We are interested in the response of the growth rates of the three variables to the shock in the growth rate of real energy prices starting from an equilibrium position. The variables we are interested in are the growth rate in real energy prices (dln(RPE)), the growth rate in energy intensity of capital (dln(E/K)), the growth rate in capital productivity (dln(Y/K)), and the growth rate in energy intensity of output (dln(E/Y)). [8] We cannot estimate the four variables of interest in one system of PVAR regression because of the collinearity– that is: the linear combination of (dln(Y/K)) and (dln(E/Y)) results in (dln(E/K)). Therefore, we estimate two separate PVARs. In the PVAR our variables are: dln(RPE), dln(E/K), and dln(E/Y) in the respective order. In the second regression, the variables included are: dln(RPE), dln(Y/K), and dln(E/Y) in the respective order. In both cases, dln(RPE) is an exogenous variable. In the first regression, dln(RPE) impacts dln(E/Y) via dln(E/K) and in the second regression via dln(Y/K). The ordering of our variables are consistent with our theoretical identification we discussed. We estimate the generalized method of moments (GMM) in both cases (Abrigo et al. (2015)).

Figure 6 presents the impulse response of dln(E/K) (left) and dln(E/Y)(right). The horizontal lines denote years. Both variables respond negatively to unexpected positive orthogonal shock to dln(RPE). We interpret this result as the capital utilization channel. As energy-cost increases, industries are induced to utilize the most energy efficient capital among the existing capital. This in turn reduces the energy used per unit of output. This

[8] The letter "d" like the Greek letter Δ denotes the growth rates (first difference in natural logarithms). Note that, at the cost of repetition, one can interpret dln(E/K) and d(ln(E/Y))) as the inverse of energy efficiency of capital and energy productivity, respectively.

result is consistent with the capital utilization theory we proposed to test.

Figure 6: Impulse response functions from panel VAR: order (dln(RPE), dln(E/K), dln(E/Y))

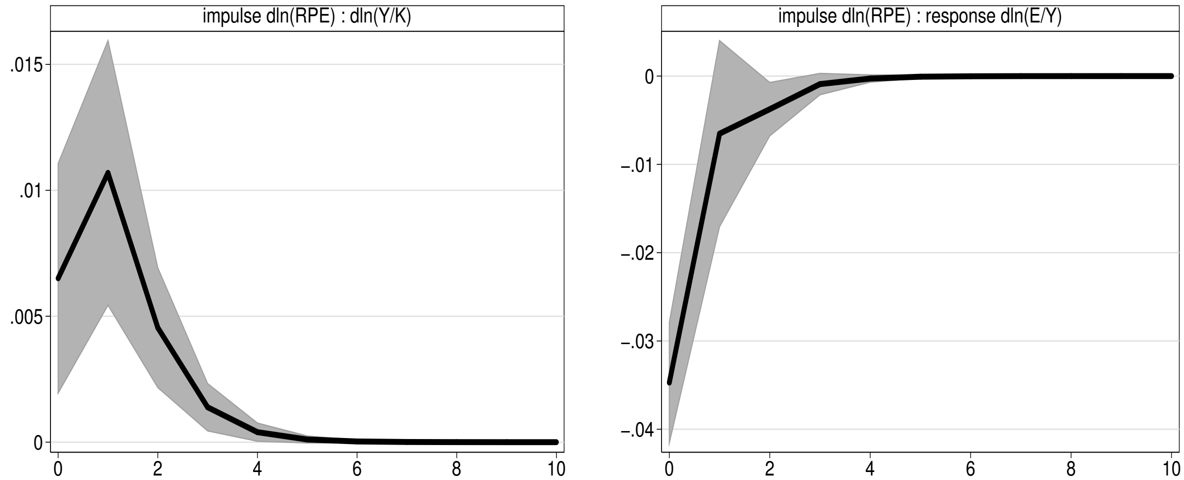


Notes: The shaded region represents 95% confidence band calculated from 1000 Monte-Carlo simulations. The orthogonal impulse response are from estimation of the variables $dln(RPE), dln(E/K), dln(E/Y)$ with one lag in GMM style with lagged instruments.

Figure 7 presents the impulse responses of dln(Y/K) (left) and dln(E/Y)(right) to dln(RPE) shock. dln(Y/K) increases after unexpected positive orthogonal shock to dln(RPE) while dln(E/Y) responds negatively to dln(RPE) shock. We interpret this result as induced investments in energy-efficient capital channel. As energy-cost increases, industries are induced to invest in energy efficient capital. These capital have higher productivity than the older capital that they replace. This in turn reduces the energy used per unit of output. This result is consistent with the induced investment theory we proposed to test.

Therefore, the panel auto regression results are consistent with both channels of increasing energy efficiency (decreasing energy intensity of output). All the impulse response functions of the estimations are presented in Appendix Two.

Figure 7: Impulse response functions from panel VAR: order (dlnRPE, dln(Y/K), dln(E/Y))



Notes: The shaded region represents 95% confidence band calculated from 1000 Monte-Carlo simulations. The orthogonal impulse response are from estimation of the variables $dln(RPE), dln(Y/K), dln(E/Y)$ with one lag in GMM style with 4 lagged instruments.

4.2.3 Co-integration and error-correction model estimation results

Table 6 presents the co-integration and error-correction model estimation results. Hausman test for model selection suggests that the pooled mean group (PMG) models are valid for the energy intensity models (ln(E/K) and ln(E/Y)) whereas the mean group (MG) is favored for the output-capital ratio model. This can be because of heterogeneity of both short- and long-run parameters in the case of the productivity of capital. These results are consistent with the heterogeneous correlations between the real energy price and capital productivity presented in appendix 5 panel B. The PMG selection of the Hauseman test is also consistent with the similar across industries correlations of energy-capital and energy-output ratios with real energy price presented in appendix 5 panel A and C.

The error-correction parameters ($\hat{\phi}$) in the models are statistically significant and negative. They also satisfy the requirement that they should be less than one in absolute. Combined, these conclude the existence of long-run (co-integrating) relationships and a return to equilibrium after an unexpected shock.

Table 6: Summary of Regression Results

	ln(E/K)		*ln(Y/K)*		*ln(E/Y)*	
	MG	PMG	MG	PMG	MG	PMG
Long-run						
$ln(RPE)$	-0.41***	-0.23***	0.10**	0.14***	-0.41***	-0.41***
$ln(RPK)$	0.15	0.37***	0.41***	0.47***	-0.20***	-0.17***
$ln(RPL)$	0.32*	0.29***	0.15	0.08***	0.33	0.11*
$ln(RPM)$	-0.41	0.27**	0.88***	0.05	-0.47	1.16***
time	-0.003	-0.01***	-0.002	-0.002***	-0.005	-0.001
Short-run						
$\Delta ln(RPE)$	-0.08	-0.23***	0.04	0.03	-0.11**	-0.24***
$\Delta ln(RPK)$	0.01	0.04	0.01	0.14***	-0.03	-0.11***
$\Delta ln(RPL)$	0.03	0.12*	0.07*	0.16***	-0.08	-0.07
$\Delta ln(RPM)$	0.31**	0.08	0.02	0.38***	0.06**	0.06
constant	0.10	-0.001	-0.11	0.04***	0.19*	0.19*
$\hat{\phi}$	-0.40***	-0.14**	-0.55***	-0.22***	-0.52***	-0.21***
Log likelihood		1608.602		2053.2		1669.8
Hausman $\chi^2(5)$	4.90		13.30		4.48	
Hausman $\chi^2(5) p > \chi^2 = 0.43$			$p > \chi^2 = 0.0.02$		$p > \chi^2 = 0.48$	

Notes: Note: *** significant at 1%; ** significant at 5%; * significant at 10%; not significantotherwise. Hausman test is for comparing the two models. Under the null, estimates from both models are consistent but mean group (MG) is inefficient. The alternative hypothesis is that pooled mean group (PMG) estimates are inconsistent. Thus, non-rejection of the null implies that PMG is consistent and hence, we can rely on its results to make inference. For the ln(E/K) and ln(E/Y) models, PMG is chosen since $Prob. > \chi^2$ is largerthan 5%. The MG estimates are used for the ln(Y/K) model since $Prob. > \chi^2$ is less than 5%.

In the long-run cointegration relationship, the energy intensity of capital is related negatively to real energy price but positively to prices of capital, labour, and materials. In the short-run, only real prices of energy and labour appear to have significant relationship, with a weaker statistical significance in the case of real price of labour. In the short-run, as real energy price increases, energy-intensity of capital decreases. There is remarkable consistency with the theoretical capital utilization channel proposed by Finn (2000) – a strong negative relationship between capital utilization and real energy price. According to the cointegration model results, in the long-run, the prices of other factors also matter. The long-run and the short-run elasticities of the energy intensity of capital with respect to the real energy price are equal. Therefore, in the context of the theoretical conjectures, the relationship between the real energy price and energy-output ratio can be a result of capital utilization adjustments channel. That is, whether it is in the long- or short-run, energy intensity of capital is influenced by energy price through the capital utilization mechanism, which in turn influences energy efficiency.

We do not find evidence for the short-run relationship between capital productivity and the real energy price. This result suggests two important hypotheses. First, the utilization effect that reduces energy intensity of capital does not decrease output-capital ratio (capital productivity). This could mean that the selective utilization of the most efficient vintages can increase capital productivity offsetting the loss of productivity from under-utilization of some vintages. Secondly, the statistically significant long-run positive effect of real energy price on capital productivity suggests the potential existence of the induced investments in new capital. In general, therefore, in the long-run, as the real prices of energy increases, the overall quality of capital stock improves. The two hypotheses reinforce the result that the long-run elasticity of energy-output ratio with respect to real energy price is larger than the short-run elasticity. Moreover, the short-run elasticities of energy-capital and energy-output ratios with respect to the real energy prices are almost equal. As stated in 6, $\frac{\partial ln(E/Y)}{\partial lnP_E} = \frac{\partial ln(E/K)}{\partial lnP_E} - \frac{\partial ln(Y/K)}{\partial lnP_E}$, in the long-run, the elasticity of energy-output ratio calculated from the data is close to the difference between the elasticity of the energy-capital ratio and the elasticity of capital productivity. However, the long-run elasticities of energy-capital and energy-output ratios with respect to the real energy price suggest that relying only on the elasticity of energy-capital ratio to predict the efficiency improvement effects can underestimate the effect of an increase in the real energy price (-0.41 is not exactly equal to -0.23 -0.14).

The central result is that, in line with the theoretical conjectures, the results strongly support the existence of strong relationship between the real energy price, energy efficiency of capital, and energy efficiency of output. The key source of improvements in the short-run seems to be the utilization adjustments whereas in the long-run, induced investments can also play important roles.

In summary of the empirical analyses, we presented qualitative and quantitative results that are consistent with the theoretical predictions. The simple correlations (aggregate and by industry), panel vector autoregressions, and panel co-integration and error-correction estimations all point out that increase in energy-costs can lead to : 1) increase in energy efficiency of capital; 2) capital productivity, and; 3) energy efficiency of output. Relating to the policy implications, carbon tax policies, which increase energy cost of industries, may eventually bring about energy efficiency of production by decreasing energy-intensity of capital and increasing output-capital ratio.

5 Conclusion

The main concern regarding carbon taxes that are considered due to global warming threats is the implied economic costs associated with the resulting rise in energy costs. The potential economic cost can be offset by energy-efficiency improvements (reductions in energy-output ratio). The key mechanism for energy efficiency improvement is through the selective utilization of the most energy efficient capital from the existing vintages as well as investments in new energy-efficient capital vintages. The energy-output ratio effect is a summary measurement that captures both mechanisms. We find these results from the Canadian data we analyzed.

The results from this study show that there is a statistically significant positive energy-price effect on the productivity of capital in the long-run. On the other hand, in the co-integration and error-correction estimations, we did not find a statistically significant relationship between output-capital ratio and energy price in the short-run. This could be considered as an evidence for the existence of induced new capital investment effect of energy cost in the long-run. In the panel vector autoregressions, we also find that the output-capital ratio increases in response to the real energy price shock.

The short- and the long-run elasticities of energy-capital ratio with respect to energy price are equal whereas the long-run elasticity of energy-output ratio is larger than the short-run elasticity (with respect to energy-price). The analytical conceptual framework we presented says that the elasticity of energy-output ratio with respect to energy price is the sum of the elasticities of energy-capital and output-capital ratios with respect to energy price.

Approximately, our result supports the analytical conjecture. We find short-run elasticities of energy-capital ratio and energy-output ratio to be -0.23 and -0.24, respectively. This result is consistent with the utilization effect of energy cost.

According to the results, a one percent rise in energy price imply a 0.23 percent reduction in energy-intensity of capital both in the short-run and in the long-run. The estimates for the energy intensity of production suggest that a one percent increase in energy price reduces energy intensity by 0.41 percent in the long-run and by 0.24 percent in the short run. In Canada, the existence of strong empirical evidence for the link between capital productivity and real energy price, as well as between energy-capital ratio and real energy price, suggests that reductions in energy-intensity of output could be due to both adjustments in utilization and induced investments.

Our results suggest that it would be possible to disentangle the long- and short-run effects of energy price on the energy-output ratio based on the long- and shor-run relationship between energy price and energy-capital ratio. Our finding of a positive effect of energy price on output-capital ratio suggests that the long-run energy efficiency improvement is due to induced investment in new capital, which improves capital productivity. On the other hand, the fact that we did not find a statistically significant short-run effect of energy price on output-capital ratio suggests that energy efficiency improvement is primarily a result of induced changes in capital utilization; more specifically, idling of energy-inefficient capital equipment.

Our study contributes to the understanding of the mechanisms by which energy price affects energy efficiency. While the theoretical conjectures are clear, their empirical tests are rarely available. Our study is a significant contribution in this respect. Our results have implications for the economic cost of the carbon tax policy which normally implys higher energy cost. A rise in energy cost leads to an improvement in capital productivity in the long-run, there by, offsetting at least part of the negative economic cost associated with carbon tax policy.

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Appendix One

Table 7: Industry specific correlations

NAICS Code	Correlation	NAICS Code	Correlation	NAICS Code	Correlation
Panel A: Correlations between E/K and real energy price by sector					
11A0	**-0.96**	2100	**-0.96**	3261	**0.60**
1130	**-0.55**	3110	**-0.94**	3262	**-0.83**
1140	0.13	3121	**-0.86**	3270	**-0.91**
1150	**0.63**	3122	**-0.74**	3310	**-0.75**
2111	**-0.25**	31A0	**-0.42**	3320	**-0.88**
2121	0.38	315- 316	**-0.92**	3330	**-0.90**
2122	**-0.92**	3210	**-0.80**	3340	**-0.94**
2123	**-0.96**	3221	**-0.81**	3350	**-0.82**
2131	**-0.36**	3231	**-0.85**	3360	**-0.89**
2211	**-0.29**	3241	-0.10	3370	-0.02
221A	**0.30**	3250	0.05	3390	**-0.93**
Panel B: Correlations between Y/K and real energy price by sector					
11A0	0.01	2100	**-0.90**	3261	**0.92**
1130	**0.75**	3110	**-0.79**	3262	**0.42**
1140	**0.52**	3121	0.10	3270	**0.56**
1150	**0.37**	3122	**-0.25**	3310	-0.10
2111	-0.12	31A0	**0.92**	3320	**0.43**
2121	**0.85**	315 - 316	-0.17	3330	**-0.27**
2122	**-0.63**	3210	**0.21**	3340	**0.77**
2123	**-0.28**	3221	-0.16	3350	**-0.65**
2131	**0.35**	3231	**-0.62**	3360	-0.10
2211	**0.36**	3241	-0.04	3370	**0.86**
221A	**-0.35**	3250	**0.37**	3390	**0.30**
Panel C: Correlations between E/Y and real energy price by sector					
11A0	**-0.99**	2100	**-0.96**	3261	**-0.94**
1130	**-0.91**	3110	**-0.94**	3262	**-0.88**
1140	-0.13	3121	**-0.85**	3270	**-0.92**
1150	**0.76**	3122	**-0.66**	3310	**-0.68**
2111	-0.14	31A0	**-0.96**	3320	**-0.93**
2121	**-0.94**	315 - 316	**-0.93**	3330	**-0.89**
2122	**-0.51**	3210	**-0.92**	3340	**-0.96**
2123	**-0.93**	3221	**-0.91**	3350	**-0.77**
2131	**-0.60**	3231	-0.10	3360	**-0.95**
2211	**-0.43**	3241	-0.10	3370	**-0.84**
221A	**0.36**	3250	**-0.67**	3390	**-0.96**

Notes: Bold-faced numbers are statistically significant

Appendix Two

Impulse response functions from panel vector autoregressions

Figure 8: Impulse response functions from panel VAR: dln(RPE), dln(E/K), dln(E/Y))

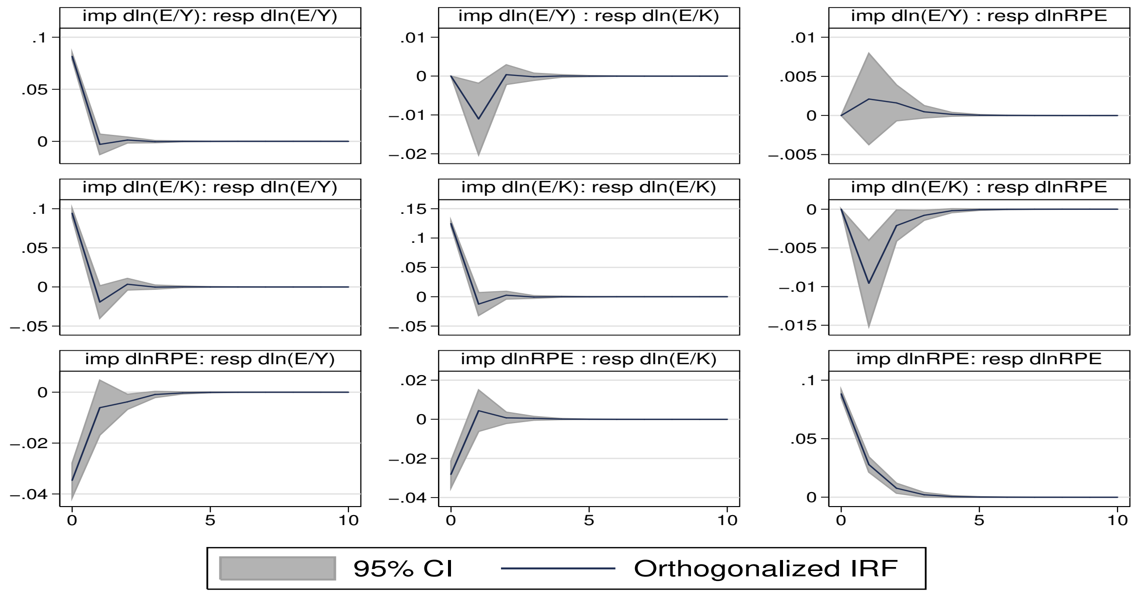

Figure 9: Impulse response functions from panel VAR:dln(RPE), dln(Y/K), dln(E/Y))