Analysis of a Small Open Economy: The Case of Energy Prices in Canada

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The analysis suggests that land rental price decrease in the long run as a consequence of higher energy prices. Energy demand from agriculture decreases if land and energy are substitute inputs. The necessary and sufficient conditions for expecting increasing average farm size, decreasing agricultural output, and number of farms also have been provided. The analysis considers a competitive equilibrium environment with specific proviso that land prices adjust in response to higher domestic energy prices. Simple expressions for calculating long-run agricultural responses to higher domestic energy prices were derived and used in estimating such responses for Canadian agriculture.

Key words: Canada, energy prices, land revenue function, profit function.

Domestic oil prices in Canada are controlled by the government substantially below world prices. However, in 1981 domestic crude oil prices increased faster than world prices. An energy pricing and taxation agreement between the governments of Canada and Alberta will allow domestic crude oil prices to rapidly approach world levels. According to this agreement, the domestic crude oil price will be 115% higher than its current level by 1985. Thus, it is important to explore the long-run implications of this price increase in Canadian agriculture.

This paper analyzes the long-run effects of increasing energy prices on land prices, average farm size, energy demand, and output responses in a small open economy such as Canada in which by assumption all internationally traded commodities have exogenous prices. Output prices, prices of intermediate inputs and farm machinery are exogenous parameters from the viewpoint of agriculture. Moreover, we also assume that agriculture is a small part of the labor market, and, consequently, labor demand from agriculture has no significant effect on the wage rate. Only agricultural land prices are endogenously determined, and the analysis concentrates on the long-run impact of increasing energy prices in a competitive equilibrium environment with specific proviso that land prices adjust in response to such increases.[1] The analysis pertains to the competitive, increasing-cost industry. We assume that all firms are identical. Thus, increasing costs occur because land prices are affected as agricultural output expands.[2]

Long-run studies of the competitive industry have followed two approaches: (*a*) the comparative statics of the firm in a competitive industry with implications for industry supply and demand responses via aggregation across firms (Silberberg, Ferguson and Saving, Bassett and Borcherding); (*b*) the comparative statics of the industry under specific assumptions about the aggregate industry technology without explicit consideration of the firms' technology or changes in firm numbers (Floyd, Timmer, Gardner). The advantage of the latter is that it is simpler. Hence, it can account for a larger number of endogenous prices. Its disadvantage is that it is ad hoc. Its assumptions about firms' production technology are not explicit, and it does not provide long-run comparative statics for firms. Most of these studies assumed constant returns to scale for the industry. Since profit maximization and perfect competition are also assumed,

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[1] The effects of changes in world commodity prices due to changes in world energy prices are ignored. The model considers domestic changes in energy prices due to, for example, changes in government-regulated energy prices, changes in taxes on energy consumption, or changes in energy import tariffs.

[2] It is assumed that farm land is variable in the long run at both the farm and aggregate agricultural levels. Therefore, its (rental) price is not regarded as economic rent.

it follows that constant returns to scale at the firm level are not consistent with their models. Hence, the assumption of industry's constant return to scale (which implies that at given factor prices the industry's supply curve is horizontal) requires that all firms be identical. Increasing output is thus provided by additional (identical) firms having same minimum average cost and, hence, the industry's supply curve is horizontal at given factor prices.

In this paper we follow approach (*a*). In contrast with most studies using approach (*a*), however, we consider an increasing-cost industry. Also, unlike the one study using this approach which did consider an increasing-cost industry (Hughes), we use a more compact method which allows us to obtain further long-run comparative static results for the representative firm and industry.

A feature of the model is that no restrictive assumptions are imposed on production technologies in obtaining many of the results. The use of duality theory allows one to avoid specific assumptions such as firm's homothetic technology, nonjoint output production or strong separability of the production technologies in inputs (i.e., a Cobb-Douglas or CES production function). This is in contrast with the studies by Muth, Floyd and, more recently, Timmer and Gardner which assume industry constant returns to scale and single output or nonjoint technologies.

In summary, although there exists a comprehensive and systematic analysis of long-run comparative statics of the constant-cost industry at both the firm and industry level, the long-run comparative static effects of (exogenous) factor price changes in an increasing cost industry have not been fully developed. This paper is a step towards filling this gap by considering the effects of increasing factor prices on long-run supply and demand responses at both the firm and industry levels. The theoretical model is used in analyzing the impact of higher energy prices on Canadian agriculture.

The Model

Consider a representative profit maximizer firm whose productive process is summarized by a variable profit function (Diewert 1974). Such a function is defined by

$$(1)\quad R(\mathbf{p},\mathbf{w};t) \equiv \max_{\mathbf{y},\mathbf{x}} [\mathbf{p}^T\mathbf{y} - \mathbf{w}^T\mathbf{x} : (\mathbf{w},\mathbf{y},t)\epsilon\tau],$$

where $\mathbf{p}$ is a vector of M output prices, $\mathbf{w}$ is the vector of N input prices excluding land prices, t is the level of land used, $\mathbf{y}$ is a vector of M output quantities, $\mathbf{x}$ is a vector of N input quantities excluding t, and τ is the closed and bounded production possibility set.

It is assumed that the firm is a price taker in all input and output markets and that land has a unit rental price, q, which is determined endogenously with respect to the industry. This rental price is the flow cost (i.e., opportunity costs, land maintenance costs, etc.) of using a unit of land in production for a period of time. The rental price is in long-run equilibrium equal to the current (annual) returns per unit of land. If a perfect rental market for land services exists, then q is also the long-run market rental price of land.

Competitive equilibrium implies that zero profit prevails in the long run, that is, $R(\mathbf{p},\mathbf{w},t) - qt = 0$.[3] That is, q is equal to the average land revenue, $\frac{R(\mathbf{p},\mathbf{w},t)}{q}$. Moreover, using the profit-mazimization condition, which requires that marginal land revenue equals the land rental price, it follows that the long-run competitive level of q is equal to the maximum average land revenue.[4] That is, satisfaction of both the zero profit condition and the profit-maximization necessary condition requires that q adjust to the point at which the average and marginal land revenues are identical. At this point the average land revenue is at its maximum. Therefore, the long-run equilibrium of the representative firm (i.e., when land prices adjust to exogenous changes) can be analyzed by assuming that the representative firm behaves in the long run as if it were an average revenue maximizer. One can define a maximum average land revenue function as

$$(2)\qquad \tilde{\pi}(\mathbf{p},\mathbf{w}) \equiv \max_t \left[\frac{R(\mathbf{p},\mathbf{w};t)}{t}\right].$$

[3] Note that $R(\mathbf{p},\mathbf{w};t)$ is by definition the current annual land returns.

[4] Profit maximization requires that $q = \frac{\partial R(\mathbf{p},\mathbf{w};t)}{\partial t}$. Thus, if $\frac{\partial R(\mathbf{p},\mathbf{w};t)}{\partial t} = q > \frac{R(\mathbf{p},\mathbf{w};t)}{t}$, then firms obtain negative profits and some firms exit the industry putting downward pressure on q. If $\frac{\partial R(\mathbf{p},\mathbf{w};t)}{\partial t} = q < \frac{R(\mathbf{p},\mathbf{w};t)}{t}$, then excess profit takes place and new firms enter pushing land prices upwards. Therefore, long-run equilibrium requires that $\frac{\partial R(\mathbf{p},\mathbf{w};t)}{\partial t} = q = \frac{R(\mathbf{p},\mathbf{w};t)}{t}$. Land average revenue is equal to its marginal revenue at the level of t which yields the maximum average revenue. This follows from the necessary conditions of maximization problem (2). Hence, zero profit prevails only when land rental prices are equal to the maximum average land revenue.

Accordingly, q adjusts in the long run to satisfy the condition

$$\tilde{\pi}(\mathbf{p},\hat{\mathbf{w}},s) = q, \tag{3}$$

where $\hat{\mathbf{w}}$ is a vector of input prices excluding energy prices and s is the price of energy inputs.

In order to complete the model we specify the following relationships:

$$-N\pi_q(\mathbf{p},\hat{\mathbf{w}},s,q) = \Psi(q), \tag{4}$$

$$-\pi_q(\mathbf{p},\hat{\mathbf{w}},s,q) = t, \tag{5}$$

$$N\pi_{\mathbf{p}}(\mathbf{p},\hat{\mathbf{w}},s,q) = Y, \tag{6}$$

$$-N\pi_s(\mathbf{p},\hat{\mathbf{w}},s,q) = E, \tag{7}$$

where N is the total number of farms, $\pi(\mathbf{p},\hat{\mathbf{w}},s,q)$ is the firm's long-run profit function (Diewert 1974), $\pi_q(\mathbf{p},\hat{\mathbf{w}},s,q) \equiv \dfrac{\partial\pi(\mathbf{p},\hat{\mathbf{w}},s,q)}{\partial q}$, $\pi_{\mathbf{p}} \equiv \dfrac{\partial\pi(\mathbf{p},\hat{\mathbf{w}},s,q)}{\partial \mathbf{p}}$, $\pi_s \equiv \dfrac{\partial\pi(\mathbf{p},\hat{\mathbf{w}},s,q)}{\partial s}$, Y is total industry output supply and E is aggregate industry demand for energy. Note that $-\pi_q(\mathbf{p},\hat{\mathbf{w}},s,q) = t$ by Hotelling's lemma.

Equation (4) is an industry equilibrium condition indicating that the industry's demand for land is equal to total supply of land. The aggregate land supply to agriculture is assumed upward sloping, i.e., $\dfrac{\partial\Psi(q)}{\partial q} > 0$. Equations (5) to (7) are an application of Hotelling's lemma providing the Marshallian demand for land of the representative farm and the industry aggregate output supply and energy demand relations, respectively.

A feature of the model represented by equations (3) to (7) is that it is recursive and hence is easy to use for comparative statics purposes. The endogenous variables are land rental prices (q), average farm size in acres (t), number of farms in the industry (N), industry output supply (Y), and industry energy demand (E). A change in s, for example, induces a change in q. Farm size in the long run is affected by both changes in s and q. Similarly, changes in s and q affect land supply and land demand per farm which, in turn, determine changes in the number of farms. Changes in the number of farms and of the representative farm's output due to changes in s and q also lead to long-run adjustments in aggregate output and energy demand.

Land Rental Prices

Differentiating (3) with respect to s, we obtain

$$\frac{\partial\tilde{\pi}(\mathbf{p},\hat{\mathbf{w}},s)}{\partial s} = \frac{\partial q}{\partial s}. \tag{8}$$

A direct application of the envelope theorem (Varian) and Hotelling's lemma in (2) yields

$$\frac{\partial\tilde{\pi}(\mathbf{p},\hat{\mathbf{w}},s)}{\partial s} = -\frac{e}{t}, \tag{9}$$

where e is the quantity of energy used by the representative firm.

Therefore, combining (8) and (9) we obtain

$$\epsilon_{qs} = -\frac{\mu_e}{\mu_t}, \tag{10}$$

where $\epsilon_{qs} \equiv \dfrac{\partial q}{\partial s}\dfrac{s}{q}$, the elasticity of the land rental price with respect to energy prices, μ_e is the share of energy costs on total sales and μ_t is the share of land costs.

Equation (10) establishes unambiguously that increasing prices of energy leads to decreasing land prices, regardless of whether land and energy are substitute or complement inputs, and for any general technology. This result is independent of whether the production technology is homothetic or not, whether one considers a single or a multi-output technology and whether the production technology is nonjoint in output or not. Although in the short run the effect of increasing energy prices on land rental prices is ambiguous if land and energy are substitutes, in the long run, however, this ambiguity is removed by using the competitive equilibrium assumption. Moreover, the effects of changes in energy prices on land prices are independent of land supply conditions. This surprising result is due to the fact that land rental prices are independent of land supply conditions as indicated by equation (2). Figure 1 illustrates the long-run equilibrium conditions of the representative firm and the land market, equation (3) to (5). The land market equilibrium is depicted in quadrant A. Quadrant B shows the representative firm's average (ALR) and marginal land revenues (MLR); and quadrant C provides the relationship between total land use(T), number of farms (N), and farm size (t). Suppose the initial land demand is given by curve D_1 and land supply by S. The short-run equilibrium land rental price is q_1. If firms maximize profit, then the representative firm equalizes

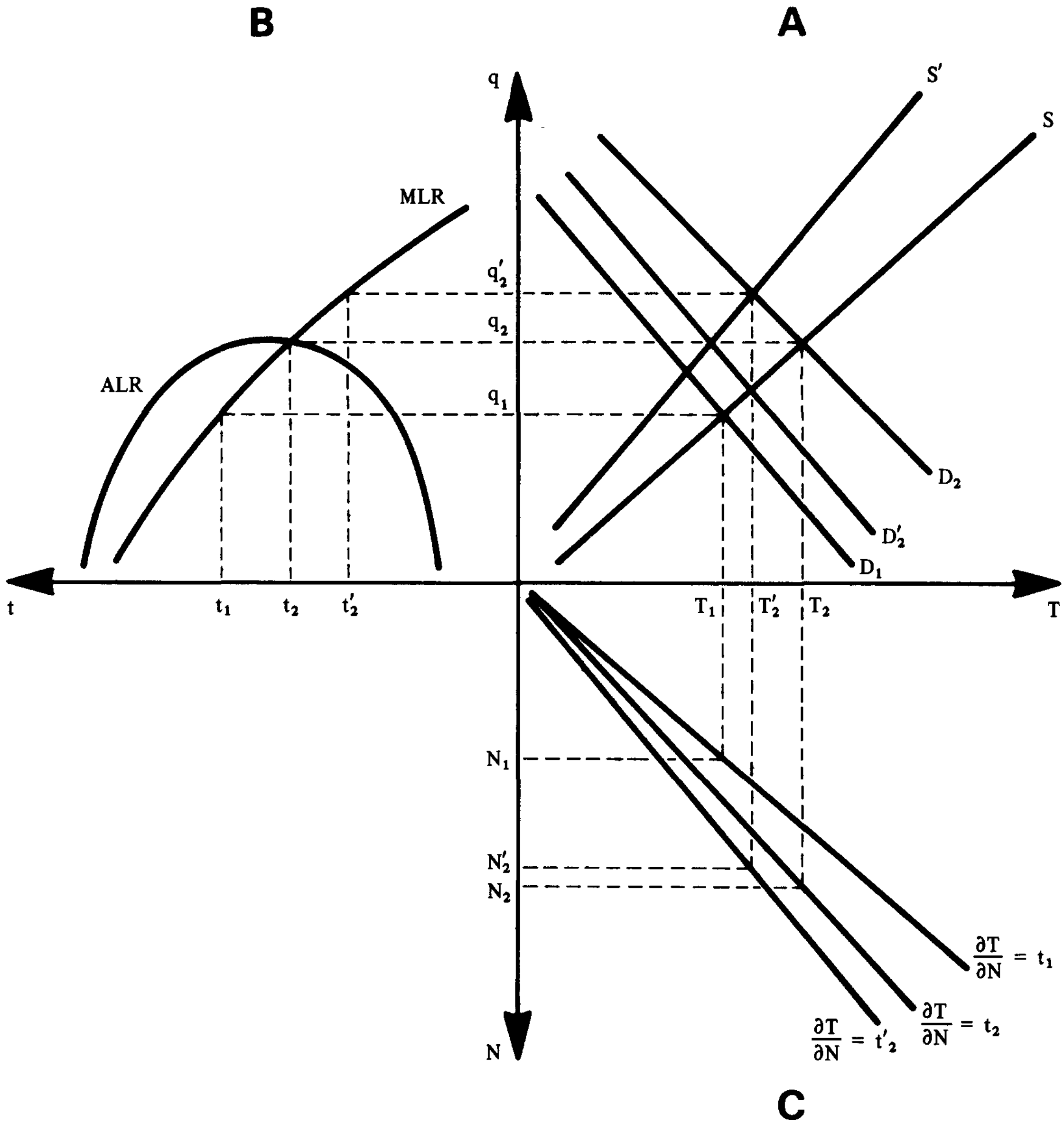

Figure 1. Determination of the long-run rental price of land, total land use and number of farms

marginal land revenue with q_1; that is, average farm size is t_1, and the number of farms consistent with a total farm land of T_1 is N_1 (quadrant C). This is not, however, a long-run equilibrium position. At t_1, firms have economic profit since the average land revenue is higher than the average land rental cost. Therefore, new firms will enter pushing the aggregate land demand to the right and increasing the land rental price towards q_2. At this price firms have no excess profits nor losses since the land rental price costs are identical to total land revenues. Thus, the land rental price is pushed to the maximum average land revenue due to competitive forces, where the representative farm size is t_2, the aggregate land use is T_2, and the equilibrium number of farms has increased to N_2. This is a long-run equilibrium situation.

To show that this equilibrium rental price is independent of land supply conditions, assume that farm land supply decreases from S to S' (say due to higher demand for land for urban or recreational purposes), and also assume land supply becomes less elastic. This shift increases the land rental price from q_2 to q_2', total land used decreases from T_2 to T_2', and farm size decreases from t_2 to t_2'. But at this point land rental costs are greater than land revenues and, hence, firms have negative profits. Some firms leave the industry, shifting aggregate land demand to the left. This process continues as long as negative profits prevail, i.e., until the new aggregate demand for land is D_2', where the original rental price q_2 prevails again. The new long-run equilibrium is achieved at the same land rental price, lower aggregate use of land, same level of land use per farm but lower number of farms. Thus, land rental prices are affected by changes in land supply in the short run, but not in the long run.

In figure 1, an increase of energy prices lowers the MLR and ALR curves and also the aggregate demand for land curve shifts inwards. However, in the short run, when N is fixed the aggregate demand curve may not shift enough to lower q to the new zero profit level. In the short run firms lose money and some exit the industry, thus decreasing further the demand for land and lowering its rental price until it becomes equal to the maximum average land revenue. Land supply elasticity only affects the number of farms which leave the industry in order to restore equilibrium. The more elastic is farm supply the greater is the reduction in the number of farms.

Farm Size

Differentiating equation (5) with respect to s and using equation (9), we obtain the long-run effect of energy prices on farm size:

$$E_{ts} = \epsilon_{ts} - \frac{\mu_e}{\mu_t}\epsilon_{tq}, \tag{11}$$

where E_{ts} is the long-run effect of a change in s on t and $\epsilon_{ts} \equiv \frac{\partial t}{\partial s}\frac{s}{t}$, and $\epsilon_{tq} \equiv \frac{\partial t}{\partial q}\frac{q}{t}$ are the (short-run) Marshallian elasticities of demand for land with respect to s and q.

Using Lopez's results (1980a) one can express (11) in terms of more basic structural relations by transforming (11) into a function of Hicksian elasticities:

$$E_{ts} = \mu_e\sigma_{te} - \mu_e\eta_{ty}\eta_{ey}\epsilon_{yp} + \mu_e\eta_{ty}^2\epsilon_{yp} - \frac{\mu_e}{\mu_t}\eta_{tq}, \tag{12}$$

where η_{tq} is the own-price Hicksian demand elasticity of land, σ_{te} is the elasticity of substitution between energy and land, η_{ty} and η_{ey} are the output elasticities of demand for land and energy, and ϵ_{yp} is the own-price short-run output supply elasticity.

Noting that the last two right-hand-side terms of (12) are non-negative (since $\epsilon_{yp} \geq 0$ and $\eta_{ty} \leq 0$ by convexity of the profit function and concavity of the underlying cost function), we conclude that increasing energy prices lead to an increase on the average farm size (i.e., $E_{ts} > 0$) if

$$\sigma_{te} \geq \eta_{ty}\eta_{ey}\epsilon_{yp}. \tag{13}$$

Moreover, since homotheticity implies that the output elasticities of all factors are identical (Silberberg), it follows that $\eta_{ty} = \eta_{ey}$ and (12) becomes

$$E_{ts} = \mu_e\sigma_{te} - \frac{\mu_e}{\mu_t}\eta_{tq}. \tag{14}$$

Thus, if the firm's production technology is homothetic, then a sufficient condition for E_{ts} to be positive is that energy and land be substitute inputs (i.e., that $\sigma_{te} > 0$).

Equation (12) provides an expression for estimating the long-run elasticity of land demand with respect to energy prices based on a weighted sum of elasticities of substitution, output elasticities of input demand, own-compensated elasticity of demand for land and factor shares. This information is usually available (12) and can have useful applications in estimating long-run changes in farm size.

The interpretation of (12) is as follows: an increase in energy prices leads to a drop in land prices. Both price changes induce changes in land demand via substitution (i.e., output constant) and output scale effects. The substitution effects are captured by the first and fourth right-hand-side terms of (12). The first term reflects the cross-substitution effect on land demand of higher energy prices. It is positive if land and energy are substitutes and negative if they are complements. The fourth term is the own-price substitution effect due to the decrease in land prices. The negative sign is due to the fact that land prices decrease. This term $\left(-\frac{\mu_e}{\mu_t}\eta_{tq}\right)$ is positive. Finally, the second and third right-hand-side terms capture the output scale effect. If neither energy nor land are inferior inputs, then the increase in energy prices has a depressing effect on output, and the associated decrease in land prices has an expanding effect. Which effect dominates depends on the magnitude of the output elasticities. If the output elasticity of land is greater than the output elasticity of energy, then the expanding effect dominates, that is, output increases. In this case the output effect on land demand is also positive and, hence, E_{ts} is positive if land and energy are substitutes. If the net effect on output is negative, then the output effect on land demand is negative; and even if $\sigma_{te} > 0$, the sign of E_{ts} is ambiguous.

Industry Output and Number of Farms

Equations (3), (4), and (6) provide a solution for the long-run equilibrium values of q, Y, and N. Totally differentiating these equations with respect to s, solving for $\partial Y/\partial s$ using Cramer's rule and expressing it in elasticity terms, we obtain:

$$(15)\quad E_{Ys} = \frac{\mu_e}{\mu_t}\left[\epsilon_{tq} - \epsilon_{yq} - \delta_{Tq}\right] + \epsilon_{ys} - \epsilon_{ts},$$

where E_{ys} is the long-run elasticity of output with respect to energy prices, ϵ_{yq} and ϵ_{ys} are the short-run firm's output supply elasticity with respect to q and s, respectively, and δ_{Tq} is the land supply own-price elasticity. Equation (15) in terms of basic structural relationships becomes

$$(16)\quad E_{Ys} = \frac{\mu_e}{\mu_t}\left[\eta_{tq} - \mu_t\epsilon_{yp}\eta_{ty}(\eta_{ty} - 1) - \delta_{Tq}\right] + \mu_e\epsilon_{yp}\eta_{ey}(\eta_{ty} - 1) - \mu_e\sigma_{te}.$$

From (16), it follows that the long-run effect of increasing energy prices on industry output supply is non-positive if and only if

$$(17)\quad \frac{1}{\mu_t}(\eta_{tq} - \delta_{Tq}) + \epsilon_{yp}(\eta_{ty} - 1)(\eta_{ey} - \eta_{ty}) \le \sigma_{te}.$$

Solving the system of equations (3), (4), and (6)—once it has been totally differentiated—for $\partial N/\partial s$ and expressing it in terms of structural elasticities, we obtain:

$$(18)\quad E_{Ns} = \frac{\mu_e}{\mu_t}(\eta_{tq} - \delta_{Tq}) - \mu_e\sigma_{te} + \mu_e\eta_{ty}\epsilon_{yp}(\eta_{ey} - \eta_{ty}),$$

where E_{Ns} is the long-run elasticity of the number of farms with respect to energy prices.

From (18) it follows that increasing energy prices have a nonpositive effect on the number of farms if and only if

$$(19)\quad \eta_{ty}\epsilon_{yp}(\eta_{ey} - \eta_{ty}) + \frac{1}{\mu_t}(\eta_{tq} - \delta_{Tq}) \le \sigma_{te}.$$

Noting that under homothetic production conditions $\eta_{ey} - \eta_{ty} = 0$, it follows that the effect of increasing energy prices on the number of farms and industry's output are both nonpositive if and only if

$$(20)\quad \frac{1}{\mu_t}(\eta_{tq} - \delta_{Tq}) \le \sigma_{te}.$$

Equations (16) and (18) provide not only the conditions for decreasing industry output and number of farms as a consequence of higher energy costs, but also they allow one to calculate long-run changes in aggregate output and number of farms in the industry by using frequently available data.

Assuming that land is not an inferior input (i.e., $\eta_{ty} \le 0$), then condition (19) suggests that the sufficient conditions for a fall in the number of farms in response to increasing energy prices are (a) that energy and land be substitutes ($\sigma_{te} \ge 0$) and (b) that the output elasticity of demand for land be greater than the output elasticity of demand for energy. Recall that an increase in energy prices is followed by a decrease in land rental prices. Thus, condition (a) ensures that both the own- and cross-substitution effects work toward increasing the representative farm demand for land. Condition (b) is related to the farm output scale effect. An increase in s reduces farm output, but the associate fall in q leads to a greater farm output. Condition (b) ensures that the farm output-expanding effect due to lower land rental prices dominates the output reduction effect due to higher energy prices. Thus, if condition (b) is satisfied, then farm output also works in the same direction as the own- and cross-substitution effects, i.e., higher land demand or, equivalently, larger farm size. Since land rental prices have decreased, total land supply to agriculture decreases, and, hence, there is less farm land available. Given that average farm size rises, the new land market equilibrium can be reached only with a smaller number of farms.

Using (17) one may verify that the sufficient conditions for a decrease in aggregate agricultural output are that $\sigma_{et} \geq 0$, and that if $\eta_{ev} > \eta_{ty}$ then the output elasticity of demand for land be less or equal to one, and if $\eta_{ev} > \eta_{ty}$ then $\eta_{ty} \geq 1$. The interpretation of these conditions is as follows. The positive elasticity of substitution ensures that direct and cross-substitution effects work in the same direction, i.e., to greater land demand and lower energy use per farm. If $\eta_{ev} > \eta_{ty}$, then the depressing energy effect on output levels dominates the expansive effects due to lower land prices. Thus, farm output falls. If farm output falls and $\eta_{ty} < 1$, then the farm demand for land decreases; but such a decrease is smaller than the fall in output per farm. Given that aggregate land supply decreases, the number of farms cannot increase proportionately more than the decrease in farm size and, consequently, if N increases such an increase is proportionately less than the fall in output per farm. Thus, if the above conditions are met, then output per farm falls and the number of farms cannot increase proportionately more than the fall in output per farm. Therefore, aggregate output decreases.

Panzar and Willig showed that if inframarginal firms exist, then Ferguson and Saving's proposition that long-run equilibrium industry's output always varies inversely with factor price does not necessarily hold. Equation (17) shows that it is not necessary to consider inframarginal firms to refute Ferguson and Saving's proposition. Even if all firms are identical, long-run output will not necessarily fall when an exogenous factor price increases in the case of an increasing cost industry.

Equation (20) indicates that if the firm's technology is homothetic, then a sufficient condition for expecting a drop in industry output is that energy and land be substitutes. It can be shown that if firm's technology is homothetic, then the firm's output in the long run is not affected by increasing energy prices.[5] However, if land and energy are substitutes, then farm size increases [equation (14)]. Furthermore, given that land prices decrease as a consequence of increasing energy costs, the total agricultural land diminishes since land supply is assumed to vary directly with its price. Hence, given that the representative farm size increases and that there are less agricultural lands available one can conclude that fewer farms will survive. Therefore, if each remaining farm produces the same output level and there are less farms remaining, then total aggregate output will decrease.

Energy Demand

The representative farm energy demand is

$$e = -\pi_s(\mathbf{p}, \hat{\mathbf{w}}, s, q). \tag{21}$$

Differentiating (21) with respect to s and using equation (10), we obtain the following result in terms of structural elasticities:

$$E_{es} = \eta_{es} - \mu_e \sigma_{et} - \mu_e \epsilon_{yp} \eta_{ev} (\eta_{ev} - \eta_{ty}), \tag{22}$$

where η_{es} is the Hicksian own-price demand elasticity of energy of the representative farm. From (22) it follows that increasing energy prices lead to a reduction of the firm's demand for energy in the long run if and only if

$$\frac{\eta_{es}}{\mu_e} - \epsilon_{yp} \eta_{ev} (\eta_{ev} - \eta_{ty}) < \sigma_{te}. \tag{23}$$

Using equation (7) one can show that the effect of energy prices on the industry demand for energy is

$$E_{ES} = E_{Ns} + E_{es}. \tag{24}$$

Hence, using equations (18) and (22) in (24), we obtain

$$E_{Es} \doteq \frac{\mu_e}{\mu_t} [\eta_{tq} - \delta_{Tq} - 2\mu_t \sigma_{te}] + \eta_{es} - \mu_e \epsilon_{yp} (\eta_{ev} - \eta_{ty})^2. \tag{25}$$

Given that $\eta_{tq} \leq 0$ and $\eta_{es} \leq 0$ by concavity of the underlying firm's cost function, $\epsilon_{yp} \geq 0$ by convexity of the profit function, one can unambiguously derive that $E_{Es} < 0$ if $\sigma_{te} \geq 0$. If $\sigma_{te} < 0$, then the sign of the long-run own-price elasticity of demand for energy is ambiguous. Thus, if energy and land are substitutes, then increasing energy costs cause a decrease in aggregate industry demand for energy.

Equation (22) shows that long-run demand for factors at the firm level are not necessarily downward sloping curves. This is in contrast with the short-run firm's derived demand curves, which are always downward sloping. Equation (23) indicates that if energy is a nor-

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[5] The firm's output supply is $y = \pi_p(\mathbf{p}, \mathbf{w}, s, q)$. Hence the long-run supply response in elasticity terms is $E_{ys} = \epsilon_{ys} - \frac{\mu_e}{\mu_t} \epsilon_{yq}$. The (short-run) elasticities ϵ_{ys} and ϵ_{yq} are: $\epsilon_{ys} = -\mu_e \epsilon_{yp} \eta_{ev}$ and $\epsilon_{yq} = -\mu_t \epsilon_{yp} \eta_{ty}$. Using these expressions on the equation for E_{ys}, we have that

$$E_{ys} = \mu_e \epsilon_{yp} \eta_{ev} - \mu_e \epsilon_{yp} \eta_{ty} = \mu_e \epsilon_{yp} (\eta_{ty} - \eta_{ev}).$$

Since homotheticity implies $\eta_{ty} = \eta_{ev}$, then $E_{ys} = 0$.

mal factor, then sufficient conditions for the long-run firm demand for energy to fall when energy prices increase are that (*a*) land and energy be substitute inputs and (*b*) that the output elasticity of demand for energy be greater than the output elasticity of demand for land. Condition (*a*) implies that both own- and cross-substitution effects affect energy demand in the same direction, i.e., towards a lower farm use of energy. Condition (*b*) ensures that the net effect of firm's output level is negative and, hence, that the indirect output effect on firm's energy demand is also negative. Thus, the long-run demand for energy at the firm level decreases if the above conditions are met.

Equation (25) indicates that the sufficient condition for expecting long-run decreasing aggregate industry energy demand in response to higher prices of energy is less restrictive than at the farm level. It suffices that energy and land be substitutes. Even if farm output increases, the negative substitution effects at the farm level and the effect of changes in number of farms on aggregate energy demand always dominate. Suppose the output elasticity of demand for land is greater than the output elasticity of demand for energy. In this case, farm output expands and, hence, the output scale effect implies higher farm energy demand. The partial effect of a 1% increase in output generates an increase in energy demand equal to η_{ey} percent. However, if $\eta_{ty} > \eta_{ey}$, then the number of farms fall [see equation (18)], thus causing a partial negative effect on aggregate energy demand. Moreover, the average farm size (in acreage) increases by η_{ty} percent for each 1% that farm output rises. Hence, the number of farms falls at least by η_{ty} percent (it may decrease more than that since the total supply of land decreases). Since $\eta_{ty} > \eta_{ey}$, then it means that the percent fall in number of farms associated with the output scale effect is greater than the percent increase in demand for energy of the representative farm. Hence, the net effect on aggregate demand for energy is negative. Thus, even if condition (2) is not satisfied, the output scale effect also points towards a lower aggregate energy demand.

Applications

Equations (10), (12), (16), (18), and (25) are used to measure the long-run impact of increasing energy prices on land rental prices, farm size, agricultural output, number of farms, and derived demand for energy in Canada. The purpose of this section is to consider the effects of a purely domestic increase of energy prices on Canadian agriculture. The question we shall try to answer is: What would be the effects of a government policy which increases domestic oil prices in order to catch up with world prices? Since the energy price increase is exclusively domestic, we are not concerned with changes in world relative prices associated with higher energy prices, and, therefore, the model can be directly applied without having to use a world model which would forecast changes in world prices. The fact that the Canadian economy is to a large extent open to international trade, and that Canadian agriculture can be considered to be a price taker in most commodity markets may allow one to use our results in answering the above question.[6] We assume land rental prices are determined in the agricultural sector. Nonfarm effects such as changes in urban demand for land or, in general, changes in the nonfarm economy on land rental prices are largely ignored.

In order to use the various equations, one needs to know the output elasticities of demand for energy and land (η_{ey} and η_{ty}), the elasticity of substitution between land and energy (σ_{et}), the short-run own-demand elasticities for energy and land (η_{es} and η_{tq}), the (short-run) own-price output elasticity (ϵ_{yp}), the shares of energy and land rental values in total sales (μ_e and μ_t), and the aggregate supply elasticity of land (δ_{Tq}). The relevant elasticities (except δ_{Tq}) are those concerning the representative farm, rather than the aggregate industry, elasticities. Unfortunately, we have been unable to find estimates for individual representative farms in Canada. Hence, we use industry estimates instead. We use here industry estimates obtained by Lopez (1980b) for η_{ey}, η_{ty}, η_{es}, η_{tq}, σ_{et} and assume a short-run output supply elasticity of 0.5 and a land supply elasticity of 0.1. These estimates were obtained using annual aggregate data for Canadian agriculture for input demands, input rental prices, and an output quantity of index for the period 1947–79.[7] The share of energy and

[6] Poultry, eggs, and dairy prices differ from world prices because of government controls. However, these commodities are not intensive users of land with the only exception of dairy.

[7] For a description of the data and procedures see Lopez (1980b). He did not disaggregate intermediate inputs into energy and nonenergy inputs. Thus, we use the elasticities for intermediate inputs of which energy is a large proportion.

Table 1. Alternative Parameter Specifications Considered

	σ_{et}	η_{ev}	η_{tv}	η_{es}	η_{tq}	ϵ_{vp}	δ_{Tq}	μ_e	μ_t
Base case	0.5	0.9	0.4	−0.6	−0.4	0.5	0.1	0.08	0.15
Alternative 1	0.0	0.9	0.4	−0.6	−0.4	0.5	0.1	0.08	0.15
Alternative 2	−0.3	0.9	0.4	−0.6	−0.4	0.5	0.1	0.08	0.15
Alternative 3	0.5	0.6	0.0	−0.6	−0.4	0.5	0.1	0.08	0.15
Alternative 4	0.5	0.9	0.4	−0.6	−0.1	0.5	0.1	0.08	0.15
Alternative 5	0.5	0.9	0.4	−0.3	−0.4	0.5	0.1	0.08	0.15

the share of the rental value of land in total farm sales (μ_e and μ_t) are 0.08 and 0.15, respectively. The industry elasticities σ_{et}, η_{es}, and η_{ts} may be expected to be greater than the firms' parameters, and hence, we use the industry estimates as upper bounds. We also use alternative combinations of the parameters in order to illustrate the sensitivity of the long-run elasticities to changes in these parameters. Table 1 provides the (short-run) elasticity specifications where the first row (base case) represents the industry estimates, and rows 2 to 6 are the alternative parameter values considered in order to analyze the sensitivity of the long-run estimates to changes in the base parameters.

The first column of table 2 presents the long-run elasticities calculated using the base case parameters. The elasticity of land rental prices with respect to energy prices is dependent only on the energy and land (rental value) shares, and, thus, its value is identical for the base case and for the six alternatives. This elasticity is −0.66, indicating that in the long run a 1% increase in energy prices would lead to a 0.66% decrease in land prices. The percentage effect of a 1% increase in s on the representative farm size is shown in row 2. This effect is 0.34 for the base case and is mildly reduced by a decrease in σ_{et}, strongly affected by a smaller short-run compensated demand elasticity (η_{tq}) and remains practically unaffected by changes in the output elasticities of demand for energy and land. The effect of energy prices on the number of farms (E_{Ns}) is negative for all alternatives, and its sensitivity pattern with respect to the different parameters is similar to E_{ts}. A change in the output elasticities of demand for energy and for land do have a significant effect in the magnitude of E_{Ys}. Smaller η_{ey} and η_{ty} tend to reduce the magnitude of the output supply response in the long run. The largest impact, however, is due to the own-price elasticity of demand for land. A reduction of η_{tq} from −0.4 to −0.1 implies a reduction of the long-run output supply elasticity from −0.38 to −0.19. Finally, the long-run industry demand for energy with respect to energy prices is quite elastic, approximately equal to −1. As can be expected, E_{Es} is responsive to changes in the firm's compensated short-run own-price demand elasticity for energy.

The results shown in table 2 have interesting policy implications. The relatively large values of E_{Es} suggest that a policy oriented to increase domestic energy prices is effective in reducing the level of energy used in agriculture. Moreover, the long-run aggregate percent decrease in energy demand is more than twice as large as the percent decrease in energy demand by the individual firm. The sacrifice in terms of agricultural output implied by a policy of increasing energy costs, however, does appear quite substantial. If energy prices double, for example, one may expect at least a 19% reduction in agricultural production. The negative effect of such a policy on

Table 2. Long-Run Elasticity Estimates with Respect to Energy Prices under Alternative Specifications for the Short-Run Parameters

Long-Run Elasticities with Respect to Energy Prices	Base Case	Alternatives				
		1	2	3	4	5
Land price (E_{qs})	−0.66	−0.66	−0.66	−0.66	−0.66	−0.66
Farm size (E_{ts})	0.24	0.20	0.18	0.24	0.08	0.24
No. of farms (E_{Ns})	−0.30	−0.26	−0.27	−0.31	−0.14	−0.30
Industry output (E_{Ys})	−0.39	−0.36	−0.35	−0.34	−0.19	−0.39
Industry energy demand (E_{Es})	−1.01	−0.89	−0.82	−1.00	−0.81	−0.71

land rental values is also very significant. Given that land is a major asset owned by farm families and, therefore, closely related to their income levels, it implies that the income of the average farm family may be substantially reduced. Hence, if a goal is to sustain farmers' income, it would be necessary to compensate farmers for such a loss using other government policies. Additionally, a policy of increasing energy costs will also lead to reinforced long-term trends observed in Canadian agriculture related to increasing farm size and decreasing the number of farms and farmers. Finally, the positive E_{ts} implies that the minimum efficient scale of operation in terms of land acreage is expanded due to higher energy costs.

Conclusions

The main results obtained for the long-run effects of changing energy prices can be generalized in terms of the long-run comparative statics of the increasing-cost industry comprised of identical firms as follows:

(*a*) The long-run effect of an increase in an exogenous factor price on the price of the factor which has a rising supply curve is nonpositive.

(*b*) In contrast with the constant-cost industry, the aggregate factor demand schedules of the increasing-cost industry are not necessarily downward sloping. A factor demand curve is downward sloping if the partial elasticity of substitution between that factor and the factor which has a rising supply curve is non-negative.

(*c*) Long-run output equilibrium does not necessarily vary inversely with factor price even if the increasing price factor is not inferior.

Conclusions (*b*) and (*c*) are important because they imply that the two well-known theorems shown by Basset and Borcherding and Ferguson and Saving, respectively, regarding that long-run factor demand schedules are always downward sloping and that industry output in the long run always varies inversely with factor price, are not universally true. These results are valid only for the constant-cost industry, but they do not necessarily hold for the increasing-cost industry.

Apart from the above results, we also have derived the necessary and sufficient conditions for expecting increasing average farm size, decreasing industry output supply and number of farms when energy prices increase. Moreover, simple expressions for calculating long-run agricultural responses to increasing energy costs in terms of short-run firm's parameters have also been provided. Finally, we have used the theoretical model in analyzing the expected long-run effect of higher energy prices on Canadian agriculture.

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References

Bassett, L. R., and T. E. Borcherding. "The Firm, the Industry and the Long-Run Demand for Factors of Production." *Can. J. Econ.* 3(1970):140–44.

Diewert, W. E. "Applications of Duality Theory." *Frontiers of Quantitative Economics*, vol. 2, ed. M. D. Intriligator and D. A. Kendrick. Amsterdam: North-Holland Publishing Co., 1974.

———. *Duality Approaches to Microeconomics.* Dep. Econ. Disc. Pap. No. 78-09, University of British Columbia, 1978.

Ferguson, C. E., and T. R. Saving. "Long-Run Scale Adjustments of a Perfectly Competitive Firm and Industry." *Amer. Econ. Rev.* 59(1969):774–83.

Floyd, J. E. "The Effects of Farm Price Supports on the Returns to Land and Labour in Agriculture." *J. Polit. Econ.* 73(1965):148–58.

Gardner, B. L. "Determinants of Supply Elasticities in Interdependent Markets." *Amer. J. Agr. Econ.* 61(1979):463–75.

Hotelling, H. "Edgeworth's Taxation Paradox and the Nature of Demand and Supply Functions." *J. Polit. Econ.* 40(1932):557–616.

Hughes, J. P. "The Comparative Statics of the Competitive Increasing-Cost Industry." *Amer. Econ. Rev.* 70(1980):318–21.

Lopez, R. E. *Estimating Substitution and Expansion Effects Using a Profit Function Approach.* Dep. Agr. Econ. Disc. Pap. No. 80-3, University of British Columbia, 1980a.

———. "The Structure of Production and the Derived Demand for Inputs in Canadian Agriculture." *Amer. J. Agr. Econ.* 62(1980b):38–45.

Muth, R. F. "The Derived Demand Curve for a Productive Factor and the Industry Supply Curve." *Oxford Econ. Pap.* 16(1965):221–34.

Panzar, J. C., and R. D. Willig. "On the Comparative Statics of a Competitive Industry with Inframarginal Firms." *Amer. Econ. Rev.* 68(1978):474–78.

Silberberg, E. "The Theory of the Firm in 'Long-Run' Equilibrium." *Amer. Econ. Rev.* 64(1974):734–41.

Timmer, C. P. "Interaction of Energy and Food Prices in a Less Developed Country." *Amer. J. Agr. Econ.* 57(1975):219–24.

Varian, H. R. *Microeconomic Analysis.* New York: W. W. Norton & Co., 1978.