A Monopolistic Competition Model of the Horticultural Industry with a Risk of Harmful Plant Invasion

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Introduction

- Growth in demand has led to expansion of the horticulture industry but has increased the risk of invasion by exotic plants (Reichard & White 2001)
- We model the North American horticulture industry using a monopolistic competition approach
- Also estimate the probability that a new introduced exotic species will become invasive, based on duration data and the characteristics for a sample of exotic plants
- We derive the privately & socially optimal number of nurseries and determine the appropriate tax rate (annual license fee) for the industry, or introducer pays tax
- We extend the work of Knowler & Barbier (2005) and revise and update a preliminary version of this research

Horticulture industry model

- Dixit-Stiglitz monopolistic competition fits the “stylized facts” of the horticulture industry (Dixit & Stigitz 1977)
- Consumers prefer a variety of differentiated plants, including exotic, imported species
- Firms (“nurseries”) are vertically integrated
- An integrated nursery firm imports plant material, propagates it and sells this differentiated product in the retail market
- Estimate the representative firm’s profit function, based on data from the US and Canadian horticulture industries

Modeling assumptions

- Nursery firms import new exotic plant species as a one-time fixed cost, ***F*****,** and produce a unique bundle of plants under increasing returns to scale
- Consumers maximize utility from the "nursery good" and a homogenous composite good
- Consumer preference for a variety of nursery goods is captured by the parameter γ, which measures substitutability between different plant bundles, with $0 < \gamma < 1$ and $\sigma = 1/(1 - \gamma) > 1$ is elasticity of substitution
- We also assume that the industry is constrained by regional resource availability, L, measured in labor units

Private industry equilibrium

- In the short run, each firm's profits are inversely related to the total number of nurseries, ***n***, in the industry:

$$\pi(n)^s = \frac{1-\gamma}{\gamma}\left(\frac{L}{n} - F\right), \quad 0 \le \gamma \le 1$$

- In the long run, industry profits are zero, and the privately optimal number of nurseries is:

$$n^p = \frac{(1-\gamma)L}{F}$$

Social welfare (I)

- Considering industry output only, then social welfare is the sum of consumers' and producers' surplus:

$$W(n) = S(n) + \Pi(n)$$

- Consumer surplus is:

$$S(n) = \left(\frac{1-\gamma}{\gamma}\right)\left(\frac{a}{\gamma}\right)^{\frac{\gamma}{\gamma-1}} n = Dn, \quad D = \left(\frac{1-\gamma}{\gamma}\right)\left(\frac{a}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}$$

where 'a' is marginal labor cost of production

- Social welfare in this case is: $W'(n^s) = 0$

Social welfare (II)

- For a social optimum, we must also consider the expected social costs from the risk of a harmful plant invasion
- The risk of a newly imported exotic species becoming invasive can be analyzed as a duration problem
- Such problems are characterized by a *hazard rate*:

$$h(t) = \lim_{\Delta t \to 0} \left\{ \mathrm{P}(\text{plant invades in } (t,\ t+\Delta t] \,|\, \text{plant has not invaded by } t) / \Delta t \right\}$$

- The hazard rate for species *k* depends on the number of nurseries selling the plant, *n(t),* and plant attributes, a_k :

$$h(t) = \varphi(n(t), a_k),\ \varphi_n > 0$$

Stochastic optimization problem

- Invasion damages, $G(\tau)$, are a function of the random time of invasion, τ :

$$G(\tau) = \int_{\tau}^{\infty} e^{-\delta(t-\tau)} cA(t)dt$$

where $A(t)$ is area invaded and 'c' is average damage per ha invaded

- The social planner maximizes the expected present value of welfare:

$$\max_{n} J = E\left\{\int_0^{\tau} W\left(n\left(t\right)\right)e^{-\delta t}dt - G\left(\tau\right)\right)e^{-\delta\tau}\right\}$$

where the expectation is taken with respect to τ

Deterministic optimization problem

- Reed and Heras (1992) transform this problem into deterministic optimal control by introducing a new state variable, ***y(t)***, with:

$$\frac{dy}{dt} = h(t) = \varphi(n(t), a_k): \quad y(0) = 0$$

- The stochastic problem now forms a standard deterministic optimal control problem:

$$\max_n J = \int_0^\infty e^{-\delta t - y(t)} \left[W(n(t)) + \delta G(\tau) \right] dt$$

subject to the above equation of motion

Welfare maximizing equilibrium and tax

- Condition for establishing the last nursery in the industry in the long run is:

$$W'(n) - h_n \frac{W(n) + \delta G(\tau)}{\delta + h(n)} = 0$$

- Substituting for $W(n)$ and rearranging gives the socially optimal number of nursery firms in the long-run:

$$n^* = \left(\frac{\Pi'(n) + D}{D} \right) \frac{\delta + h(n)}{h_n} - \frac{\Pi(n) + \delta G}{D}$$

- The introducer pays tax, χ, internalizes the expected social cost of invasion and is a form of license fee

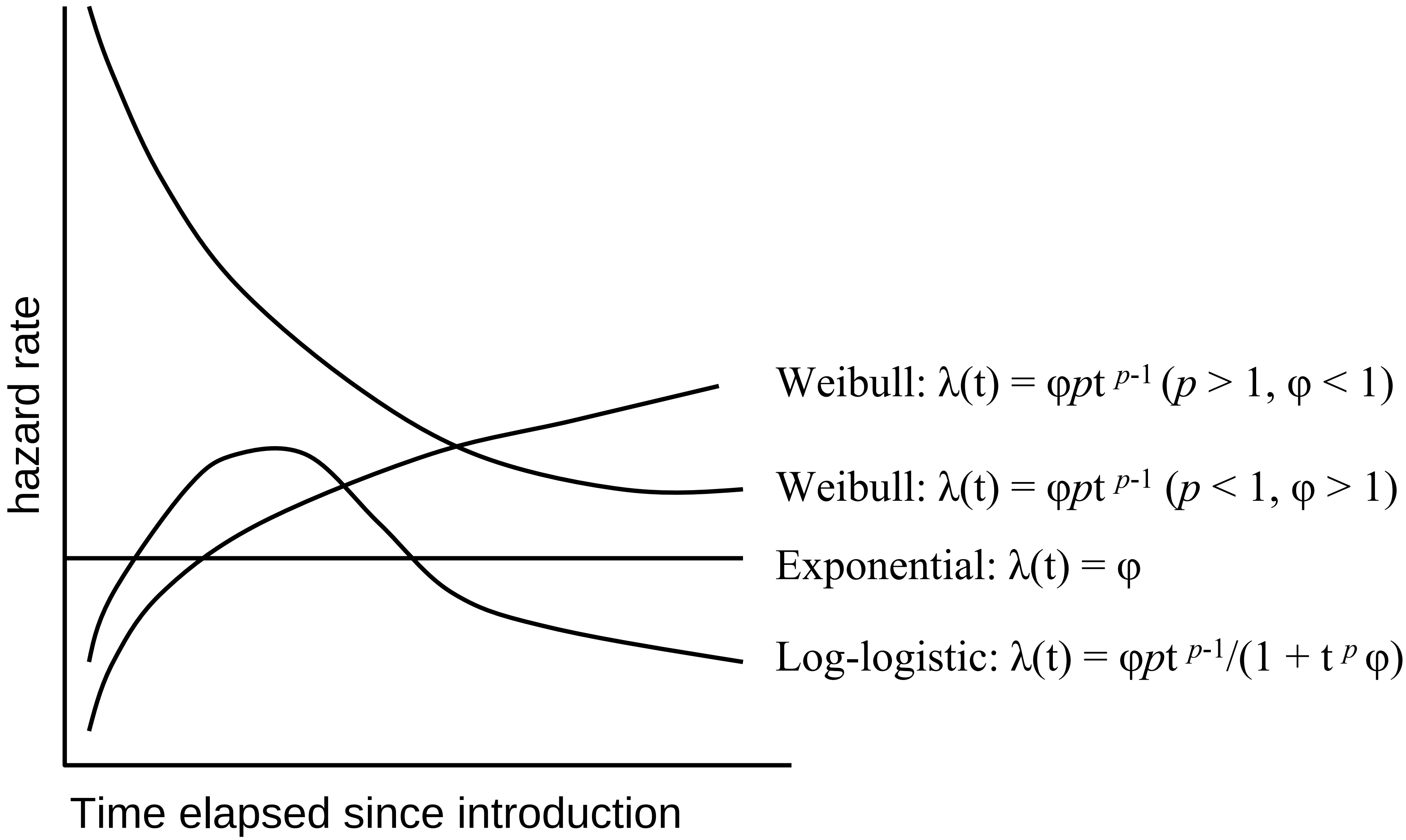
Estimating the industry profit function

- For the US and Canada we used panel data to estimate:

$$\pi(n) = b_o + b_1\left(\frac{L_{it}}{n_{it}} - F_{it}\right) + \varepsilon_{it},\ \ b_1 = (1-\gamma)/\gamma$$

- The value of γ was recovered as 0.7757 for the US and 0.1154 for Canada
- The results suggest that there is more differentiation in nursery products for the Canadian market compared to the US market

Some parametric hazard functions



Variables for herbaceous species analysis (a_k)

Name	Definition	Mean	Minimum	Maximum
Continent	Number of continents covered by native range	2	1	4
Global	Number of global bioregions already invaded	5	0	24
Annual	Plant form is annual (vs. perennial, etc.)	0.3	0	1
Flower	Length of flowering period in weeks	14.4	8	45
Selfcompatible	Flowers are selfcompatible (reproduce singly)	0.67	0	1
Polyploidy	Has more than two sets of chromosomes per nucleus	0.6	0	1
Abiotic	Fruit is dispersed abiotically (vs. biotically)	0.85	0	1
Germno	Has no specific germination requirements	0.48	0	1

Component matrix for PCA of herbaceous plant characteristic variables

Variable	Component			
	FS1	FS2	FS3	FS4
Continents	.759	-.113	-.101	-.052
Global	.668	-.043	.547	-.025
Polyploidy	.597	.240	-.121	.212
Abiotic	.147	.734	-.108	.037
Annual	-.216	.643	.464	.151
Flower	-.088	-.039	.841	.035
Selfcompatible	.009	.209	-.035	.869
Germno	-.136	.501	-.231	-.617

Regression results for herbaceous species using PCA hazard model (Dependent var. is "duration")

Variable	All Covariates				Only Significant Covariates (if any)			
	Weibull		**Exponential**		**Weibull**		**Exponential**	
	Coefficient	*p value*	*Coefficient*	*p value*	*Coefficient*	*p value*	*Coefficient*	*p value*
ONE	**5.300**	**0.000**	**5.315**	**0.000**	**5.299**	**0.000**	**5.313**	**0.000**
FS1	**-0.221**	**0.054**	**-0.252**	**0.067**	**-0.221**	**0.054**	**-0.251**	**0.067**
FS2	**0.256**	**0.014**	**0.279**	**0.023**	**0.256**	**0.014**	**0.278**	**0.023**
FS3	**-0.254**	**0.010**	**-0.275**	**0.021**	**-0.257**	**0.009**	**-0.278**	**0.020**
FS4	-0.014	0.896	-0.023	0.861				
N	106		106		106		106	
φ parameter	0.005		**0.005**		0.005		**0.005**	
p parameter	1.144		1.000		1.145		1.000	
LL	-140.298		-141.199		-140.307		-141.217	

Simulated optimal tax and number of nurseries selling a new exotic herbaceous species ($\varphi = 0.009$)

Share of profits:	***1%***	***10%***	***25%***	***50%***	***75%***	***100%***
USA						
Nurseries, n^*	34,727	31,949	27,319	19,603	11,886	4170
Firm tax ($/year)	45	446	1116	2231	3347	4462
n^*/n^p (%)	99	91	78	56	34	12
Canada						
Nurseries, n^*	3048	2856	2536	2002	1468	934
Firm tax ($/year)	49	491	1228	2456	3684	4913
n^*/n^p (%)	99	93	83	65	48	30

Summary of simulation results

- We developed a general MC framework to model the private and socially optimal number of firms in the horticulture industry when there is a risk of bioinvasion
- We then determined the optimal 'introducer pays' tax to internalize the externality
- The outcome is highly sensitive to the share of individual exotic plant sales in final profits
- Optimal US industry size is more sensitive to the tax because of greater substitutability ($\gamma_{US} > \gamma_C$) & lower CS
- An annual license fee would raise substantial revenues that could cover damage costs from a future invasion and fund screening programs for newly introduced species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