Innovation, Patents and Trade: A Firm-level Analysis

Online Appendix

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Appendix A. A model of innovation and exporting with vertical product differentiation

In Appendix A, we develop a standard vertically differentiated product model, in which the profit of firms depends on the degree of vertical and horizontal competition among the rivals (Gabszewicz and Thisse, 1979; Shaked and Sutton, 1983). In particular, an innovative firm with monopoly rights over its technologies sells a high-quality product and competes for market share against many non-innovative and lower-quality homogeneous-product rivals.

Consumers' preferences. Consider that domestic firms export in a foreign market. There exists a innovative exporter who sells its high-quality (innovative) product and holds intellectual property rights over its innovations. In turn, this firm does not face direct competition for consumers who are willing to buy innovative products. However, it faces competition from $n \geq 2$ non-innovative exporters who offer a lower-quality (non-innovative) variant of the good in this market. Thus, each of the latter firms competes vertically with the innovative monopolist and horizontally with its $n-1$ non-innovative rivals.

The market is populated by a continuum of identical consumers with mass equal to 1. The consumers are uniformly distributed along this vertical market and differ in the marginal willingness-to-pay for the product's attribute, θ_i, which is also uniformly distributed on the [0,1] interval.[1] The dispersion in θ could be driven by differences in consumer income, or in consumer preferences. We assume that the preferences of consumer i for product k are described by the indirect utility function

$$V_{ik} = \theta_i s_k - p_k,$$

where p_k is the price and s_k is the value of the attribute of product k. It is indexed by H or L depending on whether it is produced by the innovator or a non-innovative rival, respectively. The innovative firm exports a higher quality product than its non-innovative rivals, $s_H > s_L$. We also assume $s_H < ns_L$, implying that the two variants of the goods are not drastically different, allowing for intense vertical competition. Consumers purchase the variant of the product they prefer, but also have the option of making no purchase and earning a utility of zero.

[1]Fixing the upper and lower bounds of the distribution does not result in any loss of generality, given that units of product quality can be arbitrarily rescaled.

Firms' demands and profits. To derive the demand for each variant of the product, we first determine the critical value $\hat{\theta}_1$, at which a consumer is indifferent between purchasing from the innovative exporter and purchasing from a non-innovative competitor. We have $\hat{\theta}_1 s_H - p_H = \hat{\theta}_1 s_L - p_L$, implying that

$$\hat{\theta}_1 = \frac{p_H - p_L}{s_H - s_L}.$$

Thus, every consumer i with $\theta_i > \hat{\theta}_1$ will purchase from the innovative firm, whose demand function becomes $q_H = 1 - \hat{\theta}_1$. Let also $\hat{\theta}_0$ be the willingness-to-pay for quality of the consumer who is indifferent between purchasing from a non-innovative firm and not purchasing at all. We set $\hat{\theta}_0 s_L - p_L = 0$, which gives $\hat{\theta}_0 = \frac{p_L}{s_L}$. Every consumer i with a value of θ_i in the interval $\left[\hat{\theta}_0, \hat{\theta}_1\right]$ purchases from a non-innovative firm. Provided also that θ_i has a uniform distribution, the sales volume of all non-innovative firms is $Q_L = \hat{\theta}_1 - \hat{\theta}_0$, where $\hat{\theta}_1$ is given above.

To satisfy their demands, the innovative and non-innovative firms produce by bearing convex costs, $c_H q_H^2$ and $c_H q_H^2$, respectively, where $c_H < c_L$. We assume that the innovative firm has invested in product and process innovation, implying that the production of the innovative product is associated with lower cost than the production of its lower-quality variant. In addition, all firms incur an iceberg transportation cost per unit of their exports, $\tau > 1$, which can be considered as an ad valorem tax equivalent and is uniform for all firms regardless of the product's quality, such that $s_H > tc_H$ and $s_L > tc_L$.

In contrast to the literature on vertically differentiated product markets, which considers price competition among the rivals, we assume that firms compete in quantities. The finding that the Greek innovative exporters do not set substantially higher prices, whereas their higher export revenues are driven by the volume of their sales, indicates that firms compete for market share through quantities. Thus, we consider that the strategic decisions of exporters are their production levels, and express their prices as functions of their outputs:

$$p_H = (1 - q_H) s_H - Q_L s_L,$$

$$p_L = s_L\left(1 - q_H - Q_L\right),$$

where $Q_L = \sum_{i=1}^{n} q_i$ denotes the total production from all non-innovative firms. Thus, the profit functions of the innovative firm and a non-innovative competitor i are, respectively,

$$\pi_H = \left(p_H - \tau c_H q_H\right) q_H = \left[\left(1 - q_H\right) s_H - Q_L s_L - \tau c_H q_H\right] q_H$$
$$\pi_L^i = \left(p_L - \tau c_L q_L^i\right) q_L^i = \left[s_L\left(1 - q_H - q_L^i - Q_L^j\right) - \tau c_L q_L^i\right] q_L^i,$$

where $Q_L^j \equiv \Sigma_{j \neq i} q_L^j$ denotes the total output produced by the $n-1$ non-innovative rivals of firm i.

Optimal production and the effects of distance and competition. Firms choose the output level that maximizes their net profits, by solving the following n equations:

$$\begin{aligned}
\left(1 - 2q_H\right) s_H - Q_L s_L - 2\tau c_H q_H &= 0, \\
s_L\left(1 - q_H - 2q_1 - Q_L^j\right) - 2\tau c_L q_1 &= 0, \\
&\vdots \\
s_L\left(1 - q_H - 2q_{n-1} - Q_L^j\right) - 2\tau c_L q_{n-1} &= 0.
\end{aligned}$$

In equilibrium, each non-innovative competitor chooses the same output level, $q_1^* = \ldots = q_n^* = q_L^*$, reducing the $n \times n$ system of first-order conditions to

$$\left(1 - 2q_H^*\right) s_H - n q_L^* s_L - 2\tau c_H q_H^* = 0,$$
$$s_L\left[1 - q_H^* - 2q_L^* - \left(n-1\right) q_L^*\right] - 2\tau c_L q_L^* = 0.$$

We obtain the optimal quantities

$$q_H^* = \frac{1}{\lambda}\left[s_L\left(s_H + n\left(s_H - s_L\right)\right) + 2 s_H \tau c_L\right],$$
$$q_L^{i*} = \frac{s_L}{\lambda}\left(s_H + 2\tau c_H\right),$$

where $\lambda \equiv 2 s_L\left[s_H + \left(n+1\right)\tau c_H\right] + 4\tau c_L\left(s_H + \tau c_H\right) + n s_L\left(2 s_H - s_L\right)$.

Each firm's optimal quantity decreases with its own marginal cost, while it increases as rivals' production becomes more costly. The innovative firm also benefits from a quality improvement of its own product, since the quality difference between the two variants increases. The vertical competition becomes less intense, allowing the innovator to sell more.[2]

In equilibrium, the innovative firm exports more compared to a non-innovative rival, $q_H^* - q_L^* > 0$, regardless of the degree of competition among its competitors. Even if the market for the lower-grade product was also monopolized, fewer units of this product would be shipped out.[3] The transportation cost increases with distance, weakening the incentives of firms to ship their products in markets which are further away, $\frac{\partial q_H^*}{\partial \tau} > 0$ and $\frac{\partial q_L^*}{\partial \tau} > 0$. However, to analyze the effect of an increase in τ on export decisions, we need to consider the shift of the market share between the innovative and non-innovative firms. We consider the effect of an increase in τ on the equilibrium exports q_H^* and Q_L^*,

$$\frac{\partial\left(q_H^* - Q_L^*\right)}{\partial \tau} = 2\frac{n s_H s_L^2\left(c_L - c_H\right) + s_L c_H\left(4\tau c_L + s_L + 2n s_L\right)\left(n s_L - s_H\right)}{\lambda^2}$$
$$+4\frac{\left(n s_H s_L - 2\tau^2 c_L c_H\right)\left(s_H c_L - n s_L c_H\right)}{\lambda^2} > 0.$$

A higher τ decreases the total production of all non-innovative firms to a greater extent, implying that the innovative firm gains in market share in more distant markets. The Alchian-Allen-like result (shipping the good apples out) holds.

An increase in the number of non-innovative firms n that export in the same foreign market also plays a role,

$$\frac{\partial^2\left(q_H^* - Q_L^*\right)}{\partial \tau \partial n} = \frac{2 s_L\left(s_H + 2\tau c_H\right)}{\lambda^3}\left(2 s_H + s_L + 2\tau c_H\right)\left[2\left(s_L + 2\tau c_L\right)k - \lambda c_L\right]$$
$$-\frac{2 s_L c_H}{\lambda^2}\left(s_L + 2\tau c_L\right)\left(3 s_H + 4\tau c_H + s_L\right),$$

where $k \equiv (n+1) s_L c_H + 2 s_H c_L + 4\tau c_H c_L$.

Consider a numerical example where $n = 6, s_H = 30, s_L = 27, c_L = 20, c_H = 18, \tau = 1.4$, which

[2] In a setting with a high-quality dominant firm and a low-quality fringe, where firms compete in prices, Balan and Deltas (2013) show that an increase in the dominant firm's quality increases the willingness to pay of the consumers with high θ by more than those with low θ and leads to a pivoting of the inverse demand curve.

[3] We perform this analysis by considering the markets in which both types of firms are present. For instance, if only non-innovative Greek firms export say in Albania, we cannot shed insights in their export behavior.

gives $\frac{\partial^2 \left(q_H^* - Q_L^* \right)}{\partial \tau \partial n} > 0$. As the competition among the non-innovative exporters becomes more intense, the innovative firm will export more compared to its non-innovative rivals in more distant markets.

Field Code Changed

References

Balan D.J. and G. Deltas (2013): Better product at same cost, lower sales and lower welfare. *International Journal of Industrial Organization* 31(4): 322-330.

Gabszewicz J. and J-F. Thisse (1979): Price competition, quality and income disparities. *Journal of Economic Theory* 20(3): 340-359.

Shaked A. and J. Sutton (1983): Natural oligopolies. *Econometrica* 51(5): 1469-1483.

Appendix B. Additional empirical results

Table A1. Patent applications and components of export sales for products that exceed 40% of total sales in that product market (aggregation at the firm-product level)

	(1)	(2)	(3)
A. Dependent variable: *export sales*			
application	0.863***	0.868***	0.801***
	(0.201)	(0.200)	(0.216)
# destinations per firm	1.216***	1.222***	1.252***
	(0.044)	(0.051)	(0.095)
# of products per firm	0.051	0.0932*	-0.042
	(0.044)	(0.052)	(0.100)
R-squared	0.610	0.561	0.603
B. Dependent variable: *export price*			
application	0.155	0.178	0.158
	(0.114)	(0.112)	(0.118)
# destinations per firm	-0.031	-0.032	-0.040
	(0.021)	(0.025)	(0.044)
# of products per firm	-0.003	-0.022	-0.011
	(0.020)	(0.024)	(0.043)
R-squared	0.841	0.796	0.802
C. Dependent variable: *export quantity*			
application	0.709***	0.690***	0.643**
	(0.239)	(0.235)	(0.251)
# destinations per firm	1.247***	1.255***	1.291***
	(0.049)	(0.057)	(0.102)
# of products per firm	0.0535	0.115**	-0.0307
	(0.049)	(0.057)	(0.109)
R-squared	0.707	0.661	0.671
observations	8,223	5,510	1,615
# of firms	4923	2556	745

Notes: All variables are in natural logs. All regressions include a constant and product FE. Standard errors are clustered at the firm-product level. All regressions include *log(employment)*, *log(age)* and *log(assets)*. The control groups are defined as follows. Column (1): firms that sell at least one common product with *tradepat* firms. Column (2): observations of products sold by *tradepat* firms in the countries where *tradepat* firms sell. Column (3): observations of country-product pairs that match those of *tradepat* firms in the countries where *tradepat* firms sell.

Table A2. Patent applications and components of export sales (all products)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
				A. Dependent variable: *export sales*				
application	1.012***	1.036***	0.546***	1.015***	1.043***	0.539***	1.038***	0.448***
	(0.0822)	(0.0816)	(0.0779)	(0.0823)	(0.0815)	(0.0799)	(0.0972)	(0.0943)
distance		0.00302	-0.0451***		-0.0213**	-0.0700***		-0.0780***
		(0.00735)	(0.00763)		(0.0107)	(0.0111)		(0.0190)
gdp per capita		-0.0226**	-0.0508***		-0.0142	-0.0404***		0.0250
		(0.00884)	(0.00909)		(0.0129)	(0.0133)		(0.0261)
R-squared	0.254	0.243	0.283	0.221	0.208	0.250	0.254	0.295
				B. Dependent variable: *export price*				
application	-0.0620	-0.0400	0.0177	-0.0583	-0.0402	0.0451	-0.0925**	0.00590
	(0.0393)	(0.0396)	(0.0410)	(0.0392)	(0.0393)	(0.0417)	(0.0430)	(0.0473)
distance		0.0125***	0.0221***		0.0209***	0.0308***		0.0236***
		(0.00298)	(0.00300)		(0.00449)	(0.00456)		(0.00749)
gdp per capita		0.142***	0.145***		0.123***	0.126***		0.135***
		(0.00348)	(0.00355)		(0.00502)	(0.00513)		(0.00988)
R-squared	0.798	0.794	0.798	0.747	0.744	0.744	0.761	0.757
				C. Dependent variable: *export quantity*				
application	1.074***	1.076***	0.528***	1.073***	1.083***	0.494***	1.130***	0.442***
	(0.102)	(0.101)	(0.0969)	(0.102)	(0.101)	(0.0988)	(0.117)	(0.114)
distance		-0.00953	-0.0672***		-0.0422***	-0.101***		-0.102***
		(0.00816)	(0.00841)		(0.0118)	(0.0122)		(0.0209)
gdp per capita		-0.165***	-0.196***		-0.138***	-0.166***		-0.110***
		(0.0103)	(0.0106)		(0.0149)	(0.0155)		(0.0294)
R-squared	0.517	0.511	0.538	0.452	0.445	0.473	0.465	0.494
observations	162,226	162,226	152,588	75,522	75,522	70,280	24,142	22,559
# of firms	6,010	6,010	4,634	6,006	6,006	4,616	3,675	3,032

Notes: See Table 3 in the paper for further details.

Table A3. The effects of destination, distance and competition on export quantities (all products)

	Dependent variable: *export quantity*							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Distant	Close	Distant	Close		Distant	Close	
application X high_comp	**0.563*****	**-0.239**	**0.647*****	**-0.238**	**0.0151**	**0.470****	**0.105**	**0.0456**
	(0.148)	**(0.238)**	**(0.151)**	**(0.237)**	**(0.215)**	**(0.202)**	**(0.297)**	**(0.299)**
application X distant X high_comp					**0.613****			**0.448**
					(0.241)			**(0.351)**
application	0.271**	0.797***	0.193	0.767***	0.471**	0.248	0.404	0.368
	(0.117)	(0.212)	(0.119)	(0.212)	(0.189)	(0.171)	(0.269)	(0.272)
distant					-0.176**			-0.465
					(0.0736)			(0.300)
high_comp	0.571***	0.260***	0.488***	0.261***	0.443***	0.523***	0.0809	0.208
	(0.0337)	(0.0456)	(0.0501)	(0.0856)	(0.0742)	(0.136)	(0.354)	(0.287)
application X distant					-0.194			-0.0881
					(0.199)			(0.315)
distant X high_comp					-0.101			0.151
					(0.0835)			(0.309)
patent strength	0.340***	0.681***	0.245	0.619***	0.548***	1.232***	1.092***	1.137***
	(0.127)	(0.128)	(0.169)	(0.199)	(0.120)	(0.450)	(0.406)	(0.286)
observations	66,830	58,396	30,920	25,827	56,747	8,147	9,912	18,059
R-squared	0.603	0.533	0.528	0.466	0.484	0.574	0.460	0.504

Notes: See Tables 4 and 6 for further details on variables' definitions and estimation details.

Table A4. Patent applications and components of export sales (1% trimming)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
				A. Dependent variable: *export sales*				
application	1.007***	1.027***	0.548***	1.007***	1.033***	0.532***	1.020***	0.441***
	(0.0834)	(0.0823)	(0.0784)	(0.0834)	(0.0822)	(0.0802)	(0.0992)	(0.0945)
distance		-0.00551	-0.0527***		-0.0353***	-0.0856***		-0.0807***
		(0.00800)	(0.00830)		(0.0111)	(0.0114)		(0.0193)
gdp per capita		-0.0516***	-0.0846***		-0.0221*	-0.0504***		0.0326
		(0.00955)	(0.00982)		(0.0134)	(0.0138)		(0.0262)
R-squared	0.241	0.230	0.268	0.218	0.205	0.248	0.257	0.298
				B. Dependent variable: *export price*				
application	-0.0651	-0.0414	0.0223	-0.0605	-0.0410	0.0492	-0.100**	-0.00137
	(0.0399)	(0.0402)	(0.0419)	(0.0398)	(0.0398)	(0.0423)	(0.0432)	(0.0476)
distance		0.0130***	0.0246***		0.0211***	0.0330***		0.0266***
		(0.00343)	(0.00346)		(0.00481)	(0.00489)		(0.00765)
gdp per capita		0.148***	0.153***		0.125***	0.129***		0.133***
		(0.00401)	(0.00410)		(0.00535)	(0.00544)		(0.01000)
R-squared	0.757	0.752	0.757	0.724	0.720	0.722	0.753	0.749
				C. Dependent variable: *export quantity*				
application	1.072***	1.068***	0.526***	1.067***	1.074***	0.483***	1.120***	0.442***
	(0.104)	(0.103)	(0.0984)	(0.104)	(0.102)	(0.0996)	(0.120)	(0.115)
distance		-0.0185**	-0.0773***		-0.0563***	-0.119***		-0.107***
		(0.00902)	(0.00929)		(0.0124)	(0.0128)		(0.0213)
gdp per capita		-0.199***	-0.237***		-0.147***	-0.179***		-0.100***
		(0.0113)	(0.0117)		(0.0155)	(0.0160)		(0.0295)
R-squared	0.480	0.474	0.503	0.433	0.427	0.458	0.463	0.493
	1.072***	1.068***	0.526***	1.067***	1.074***	0.483***	1.120***	0.442***
observations	136,583	136,583	128,191	70,246	70,246	65,377	22,977	21,488
# of firms	5,676	5,676	4,381	5,615	5,615	4,320	3,473	2,866

Notes: See Table 3 in the paper for further details.

Table A5. The effects of destination, distance and competition on export quantities (1% trimming)

	Dependent variable: *export quantity*							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Distant	Close	Distant	Close		Distant	Close	
application X high_comp	**0.667*****	**-0.240**	**0.695*****	**-0.240**	**0.0336**	**0.536****	**0.0476**	**-0.0145**
	(0.152)	**(0.245)**	**(0.154)**	**(0.244)**	**(0.220)**	**(0.217)**	**(0.304)**	**(0.304)**
application X distant X high_comp					**0.636*****			**0.550**
					(0.246)			**(0.363)**
application	0.223*	0.789***	0.150	0.750***	0.453**	0.197	0.445	0.434
	(0.117)	(0.220)	(0.119)	(0.220)	(0.193)	(0.182)	(0.277)	(0.277)
distant					-0.185**			-0.463
					(0.0763)			(0.308)
high_comp	0.491***	0.188***	0.463***	0.202**	0.409***	0.501***	0.112	0.231
	(0.0388)	(0.0503)	(0.0521)	(0.0870)	(0.0762)	(0.141)	(0.357)	(0.292)
application X distant					-0.225			-0.191
					(0.203)			(0.323)
distant X high_comp					-0.0694			0.140
					(0.0862)			(0.317)
patent strength	0.0191	0.367***	0.119	0.329	0.410***	1.150**	1.169***	1.169***
	(0.133)	(0.134)	(0.168)	(0.205)	(0.121)	(0.479)	(0.401)	(0.290)
observations	52,838	51,526	27,699	24,675	52,374	7,376	9,704	17,080
R-squared	0.565	0.496	0.510	0.450	0.466	0.574	0.458	0.503

Notes: See Tables 4 and 6 for further details on the definitions of the variables and estimation details.