WEB APPENDIX

"Patent Protection, Complementary Assets, and Firms' Incentives for Technology Licensing"

Ashish Arora and Marco Ceccagnoli

Table A1. GMM structural estimates of the system of patent and licensing propensity equations: Instrumental variable estimation.

	$V_L - V_S$			$V_P - V_S$		
	Endog. ρ	Endog. θ	Endog. θ and ρ	Endog. ρ	Endog. θ	Endog. θ and ρ
Intercept	−5.046**	−5.084**	−5.923**	−2.456**	−3.982**	−3.702**
	(0.744)	(0.622)	(1.303)	(0.431)	(0.595)	(0.678)
Patent effectiveness	2.431*	4.086**	5.195**	1.526**	4.289**	4.437**
	(1.024)	(1.077)	(1.761)	(0.473)	(1.137)	(1.131)
Complementary assets	0.098	−0.025	1.397	−2.210*	−0.138	−1.450
	(1.064)	(0.569)	(1.450)	(0.997)	(0.572)	(1.269)
Log business unit employees	0.023	−0.004	0.008	0.099**	0.136**	0.137**
	(0.045)	(0.047)	(0.048)	(0.030)	(0.033)	(0.039)
Patent effectiveness × Complementary assets	−0.253	−0.695	−2.778	2.835[a]	0.170	2.194
	(1.709)	(1.035)	(2.289)	(1.514)	(1.153)	(2.100)
No. of technological rivals	−0.018	−0.020	−0.030	−0.033**	−0.031**	−0.025*
	(0.018)	(0.018)	(0.021)	(0.011)	(0.009)	(0.011)
% basic R&D	2.718**	2.345**	2.446**	−0.951	−1.872*	−2.183*
	(0.783)	(0.898)	(0.935)	(0.836)	(0.945)	(1.026)
Importance of medical/health science	0.305**	0.316**	0.287**	−0.132[a]	−0.169*	−0.184*
	(0.101)	(0.099)	(0.096)	(0.078)	(0.084)	(0.093)
Importance of basic science	0.321**	0.225*	0.249*	−0.063	−0.095	−0.145[a]
	(0.099)	(0.107)	(0.105)	(0.060)	(0.069)	(0.081)
Parent firm is global	−0.161	−0.219	−0.097	0.448**	0.338*	0.291
	(0.189)	(0.193)	(0.200)	(0.144)	(0.159)	(0.182)
Parent firm is foreign	0.052	0.143	0.073	0.313	0.265	0.356
	(0.301)	(0.354)	(0.341)	(0.212)	(0.215)	(0.254)
Parent firm is public	0.286	0.383	0.330	0.417**	0.418**	0.506**
	(0.250)	(0.274)	(0.261)	(0.152)	(0.148)	(0.186)
Industry Fixed Effects (7)	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*
N = 757						

Note: Standard errors in parentheses. **, *, [a]: Significantly different than zero at the 0.01, 0.05, and 0.10 confidence levels.

Table A2. GMM structural estimates of the system of patent and licensing propensity equations: Controlling for R&D.

	$V_L - V_S$		$V_P - V_S$	
	I	II	I	II
Intercept	−3.871**	−4.175**	−2.605**	−3.296**
	(0.671)	(0.607)	(0.330)	(0.311)
Patent effectiveness	2.552**	2.601**	2.035**	2.072**
	(0.485)	(0.487)	(0.262)	(0.260)
Complementary assets	−0.168	−0.271	−0.541**	−0.628**
	(0.312)	(0.322)	(0.188)	(0.188)
Log business unit employees	−0.058	−0.016	0.036	0.116**
	(0.066)	(0.052)	(0.034)	(0.030)
Patent effectiveness × Complementary assets	−0.658	−0.604	0.978**	1.037**
	(0.570)	(0.572)	(0.372)	(0.372)
No. of technological rivals	−0.007	−0.007	−0.031*	−0.030*
	(0.020)	(0.018)	(0.013)	(0.013)
% basic R&D	2.678*	2.397*	−1.805[a]	−1.434
	(1.127)	(1.100)	(1.043)	(1.026)
Importance of medical/health science	0.267*	0.257*	−0.114	−0.103
	(0.107)	(0.105)	(0.078)	(0.079)
Importance of basic science	0.226[a]	0.254*	−0.077	−0.041
	(0.125)	(0.129)	(0.062)	(0.062)
Parent firm is global	−0.085	−0.078	0.283[a]	0.379*
	(0.205)	(0.203)	(0.146)	(0.147)
Parent firm is foreign	−0.285	−0.220	0.388[a]	0.466*
	(0.323)	(0.338)	(0.212)	(0.211)
Parent firm is public	0.044	0.138	0.473**	0.556**
	(0.254)	(0.272)	(0.161)	(0.166)
Business unit R&D[1]	0.078	0.016	0.162**	−0.017
	(0.067)	(0.041)	(0.043)	(0.017)
Industry Fixed Effects (7)	*YES*	*YES*	*YES*	*YES*

Notes:
1. Specification I (for which N = 752) includes the log of business unit R&D among the explanatory variables, whereas specification II (for which N = 730) uses R&D intensity (R&D over sales).
2. Standard errors in parentheses. **, *, [a]: Significantly different than zero at the 0.01, 0.05, and 0.10 confidence levels.

Table A3. Correlated Payoffs: GMM estimates of the generalized extreme value model.[†]

	$V_L - V_S$	$V_P - V_S$
Intercept	−4.913**	−3.269**
	(1.808)	(0.397)
Patent effectiveness	2.464**	2.179**
	(0.449)	(0.247)
Complementary assets	−0.100	−0.616**
	(0.475)	(0.200)
Log business unit employees	−0.004	0.117**
	(0.090)	(0.037)
Patent effectiveness × Complementary assets	−0.584	1.002*
	(1.197)	(0.438)
No. of technological rivals	−0.020	−0.031**
	(0.017)	(0.010)
% basic R&D	2.699	−0.736
	(2.423)	(1.056)
Importance of medical/health science	0.316	−0.122
	(0.294)	(0.105)
Importance of basic science	0.346	−0.064
	(0.299)	(0.084)
Parent firm is global	−0.129	0.445*
	(0.414)	(0.187)
Parent firm is foreign	0.103	0.349[a]
	(0.360)	(0.209)
Parent firm is public	0.293	0.475**
	(0.296)	(0.153)
Sigma (σ)	−0.017 (0.915)	
Industry fixed effects (7)	*YES*	*YES*
N = 757		

Notes:

1. These estimates relate to an extended version of the system of equations 4-1 and 4-2 presented in the text, where we allow similar alternatives to be correlated. This is known as the Generalized Extreme Value model (Maddala 1983, pp. 70-72). The presented estimates refer to the case where V_L and V_P are allowed to be correlated. Similar results are obtained by allowing V_P and V_S to be correlated. The probability of patenting and licensing, in this model, are obtained as follows:

$$P_{PAT} = \frac{1 + e^{\frac{V_P - V_L}{1-\sigma}} \left(e^{\frac{V_S - V_L}{1-\sigma}} + e^{\frac{V_P - V_L}{1-\sigma}} \right)^{-\sigma}}{1 + \left(e^{\frac{V_S - V_L}{1-\sigma}} + e^{\frac{V_P - V_L}{1-\sigma}} \right)^{1-\sigma}}; P_{LIC} = \frac{1}{1 + \left(e^{\frac{V_S - V_L}{1-\sigma}} + e^{\frac{V_P - V_L}{1-\sigma}} \right)^{1-\sigma}}.$$

The parameter σ varies between zero and one, and it is higher, the higher the correlation between V_L and V_P. For the case of σ=0, these probabilities are the same as the multinomial logit probabilities (3-1 and 3-2). Our estimate of σ is slightly negative, although very close to zero, with a high standard error. We cannot reject the null hypothesis that σ is equal zero, thus supporting the use of our benchmark specification.

1) Standard errors in parentheses. **, *, [a]: Significantly different than zero at the 0.01, 0.05, and 0.10 confidence levels.

Table A4. GMM estimates of the probability of licensing conditional on patenting as a single equation.[†]

	$V_L - V_P$
Intercept	0.314
	(0.482)
Patent effectiveness	−0.523
	(0.473)
Complementary assets	−0.097
	(0.368)
Log business unit employees	−0.058
	(0.037)
Patent effectiveness × Complementary assets	−0.212
	(0.64)
No. of technological rivals	0.012
	(0.017)
% basic R&D	1.529*
	(0.759)
Importance of medical/health science	0.102
	(0.086)
Importance of basic science	0.108
	(0.08)
Parent firm is global	−0.117
	(0.158)
Parent firm is foreign	−0.48[a]
	(0.287)
Parent firm is public	−0.373[a]
	(0.197)
Industry fixed effects (7)	*YES*
N = 574	
Adj-R^2 = 0.02	

Notes:

1. The probability of patenting conditional on patenting is: $P_{L|PAT} = 1/\left[1 + e^{-(V_L - V_P)}\right]$. The dependent variable used is the licensing propensity divided patent propensity, which leads us to drop the non-patentees.
2. Standard errors in parentheses. **, *, [a]: Significantly different than zero at the 0.01, 0.05, and 0.10 confidence levels.

Table A5. GMM structural estimates of the system of patent and licensing propensity equations: Estimates within groups of firms with low and high specialized complementary assets.

	$V_L - V_S$		$V_P - V_S$	
	LOW COMPL. ASSETS	HIGH COMPL. ASSETS	LOW COMPL. ASSETS	HIGH COMPL. ASSETS
Intercept	−3.637**	−5.049**	−3.049**	−4.008**
	(0.711)	(0.568)	(0.392)	(0.419)
Patent effectiveness	2.808**	1.271**	2.065**	3.307**
	(0.517)	(0.455)	(0.268)	(0.316)
Log business unit employees	−0.052	0.015	0.114**	0.113*
	(0.07)	(0.066)	(0.037)	(0.05)
No. of technological rivals	0.002	−0.045[a]	−0.03	−0.026[a]
	(0.024)	(0.027)	(0.02)	(0.016)
% basic R&D	0.017	7.88**	−2.338[a]	−0.649
	(1.284)	(1.332)	(1.276)	(1.532)
Importance of medical/health science	0.258[a]	0.214	−0.151	−0.061
	(0.141)	(0.173)	(0.10)	(0.124)
Importance of basic science	0.264	0.334*	−0.031	−0.087
	(0.17)	(0.155)	(0.072)	(0.102)
Parent firm is global	−0.076	−0.106	0.314[a]	0.354[a]
	(0.276)	(0.318)	(0.195)	(0.203)
Parent firm is foreign	−0.655	0.312	0.21	0.653
	(0.527)	(0.411)	(0.306)	(0.29)
Parent firm is public	−0.013	0.277	0.322	0.773**
	(0.379)	(0.322)	(0.241)	(0.229)
Industry fixed effects (7)	*YES*	*YES*	*YES*	*YES*

Notes:
1. N=380 for the sub-group of low complementary assets firms; N = 377 for the sub-group of high complementary assets firms.
2. Consistent with hypothesis 1A, patent effectiveness increases $V_P - V_S$ and $V_L - V_S$. Consistent with hypothesis 2A, the impact of patent effectiveness on $V_P - V_S$ is higher for high complementary asset firms relative to firms with low complementary assets.
3. Standard errors in parentheses. **, *, [a]: Significantly different than zero at the 0.01, 0.05, and 0.10 confidence levels.

Table A6. GMM structural estimates of the system of patent and licensing propensity equations: Estimates using the effectiveness of complementary manufacturing capabilities as an alternative measure of complementary assets

	$V_L - V_P$	$V_P - V_S$
Intercept	–4.529**	–3.601**
	(0.540)	(0.275)
Patent effectiveness	2.726**	2.590**
	(0.429)	(0.236)
Complementary assets	0.271	–0.076
	(0.311)	(0.201)
Log business unit employees	–0.008	0.121**
	(0.051)	(0.028)
Patent effectiveness * Complementary assets	–0.747	0.050
	(0.577)	(0.393)
No. of technological rivals	–0.004	–0.033**
	(0.019)	(0.012)
% basic R&D	2.852**	–1.386
	(1.036)	(1.003)
Importance of medical/health science	0.270*	–0.111
	(0.107)	(0.076)
Importance of basic science	0.244*	–0.048
	(0.124)	(0.061)
Parent firm is global	–0.125	0.389**
	(0.192)	(0.142)
Parent firm is foreign	–0.209	0.430*
	(0.323)	(0.208)
Parent firm is public	0.183	0.552**
	(0.257)	(0.162)
Industry fixed effects (7)	*YES*	*YES*
N=757		

Notes:

1. The CMS asks respondents to indicate the % of their product and process innovations for which *complementary manufacturing facilities and know-how* had been effective in protecting their firm's competitive advantage from those innovations during the prior three years. There were five mutually exclusive response categories for product and process innovations separately: <10%, 10-40%, 41-60%, 61-90%, >90%. We compute a weighted average of the product and process scores (using mid points), with the % of R&D effort devoted to product and process innovations as weights, to construct this alternative measure of a firm's specialized complementary assets.
2. Elasticities computed using these structural estimates show that the main result of the paper, summarized by table 6 in the main text for the benchmark case, still holds. In particular, the elasticity of the probability of licensing decreases from 0.55 to 0.33 when computed for low and high complementary assets firms. Similarly, the probability of licensing conditional on patenting decreases from 0.04 to –0.2 when computed for low and high complementary assets firms.
3. Standard errors in parentheses. **, *, [a]: Significantly different than zero at the 0.01, 0.05, and 0.10 confidence levels.

- A model with sequential decisions.

Let the payoff from licensing be $V_L+\varepsilon_L$ and from patenting and not licensing be $V_P+\varepsilon_P$. We assume that ε_P and ε_L are not observed at the time of patenting but are observed when licensing. Conditional on patenting, licensing takes place if $\varepsilon_L-\varepsilon_P>V_P-V_L$. Let $\eta = \varepsilon_L-\varepsilon_P$ be $N(0, \sigma_\eta^2)$, with $\sigma_\eta^2 = \sigma_L^2+\sigma_P^2 - 2\sigma_{LP}$, which also reflects the degree of uncertainty in the net payoffs from licensing at the time of patenting. The probability of licensing conditional on patenting is equal to $P_{L|P}= 1 - \Phi[(V_P-V_L)/\sigma_\eta]$. The payoff from not patenting is $V_S+\varepsilon_S$. Therefore, one patents if $(V_L+\varepsilon_L^*)P_{L|P} + (V_P+\varepsilon_P^*)(1-P_{L|P}) > V_S+\varepsilon_S$, where (cf. Greene 2003: 781 and Maddala 1983: 367):

$$\varepsilon_L^* = E(\varepsilon_L \mid \varepsilon_L-\varepsilon_P > V_P - V)_L = \frac{Cov(\varepsilon_L, \varepsilon_L-\varepsilon_P)}{\sqrt{Var(\varepsilon_L-\varepsilon_P)}}\frac{\phi(z)}{1-\Phi(z)} = \frac{\sigma^2_{\varepsilon_L}-\sigma_{LP}}{\sqrt{\sigma^2_{\varepsilon_L}+\sigma^2_{\varepsilon_P}-2\sigma_{LP}}}\frac{\phi(z)}{1-\Phi(z)},$$

$$\varepsilon_P^* = E(\varepsilon_P \mid \varepsilon_L-\varepsilon_P < V_P - V_L) = \frac{Cov(\varepsilon_P, \varepsilon_L-\varepsilon_P)}{\sqrt{Var(\varepsilon_L-\varepsilon_P)}}\frac{-\phi(z)}{\Phi(z)} = \frac{\sigma^2_{\varepsilon_P}-\sigma_{LP}}{\sqrt{\sigma^2_{\varepsilon_L}+\sigma^2_{\varepsilon_P}-2\sigma_{LP}}}\frac{\phi(z)}{\Phi(z)},\ z = \frac{V_P-V_L}{\sqrt{\sigma^2_{\varepsilon_L}+\sigma^2_{\varepsilon_P}-2\sigma_{LP}}};$$

$$\Pr(Patent) = \Phi\left\{V_P - V_S - (V_P - V_L)[1-\Phi(z)] + \varepsilon_L^*[1-\Phi(z)] + \varepsilon_P^*([\Phi(z)])\right\} = \Phi\left\{V_P - V_S - (V_P - V_L)[1-\Phi(z)] + \sigma_\eta\phi(z)\right\}$$

The system to estimate then becomes:

$$\begin{cases} P_P = \Phi\{V_P - V_S - (V_P - V_L)[1-\Phi(z)] + \sigma_\eta\phi(z)\} \\ P_L = [1-\Phi(z)]\Phi\{V_P - V_S - (V_P - V_L)[1-\Phi(z)] + \sigma_\eta\phi(z)\} \end{cases}$$

with $z = \frac{V_P-V_L}{\sigma_\eta}$ and $\sigma_\eta = \sqrt{\sigma^2_{\varepsilon_L}+\sigma^2_{\varepsilon_P}-2\sigma_{LP}}$. To estimate it we normalize $\text{Var}(\varepsilon_S) = 1$.

Estimates of this model lead to results that are similar to our benchmark model. Although the sequential specification introduces additional nonlinearities (with standard errors that are larger for the effects on licensing), estimates from Table A7 show that the signs of the interaction effect between patent effectiveness and complementary assets (negative on V_L-V_P and positive on V_P-V_S) are still as expected. The estimate of σ_η is not significantly different than zero, implying either that the degree of uncertainty in licensing payoffs at the time of patenting is low, or, more likely, that the model and the data are not able to capture the underlying uncertainty. Further analysis and data on this issue is required.

Table A7. Sequential Licensing Model: GMM estimates.

	V_L-V_P	V_P-V_S
Intercept	−0.883 (0.904)	−1.911** (0.218)
Patent effectiveness	0.158 (0.284)	1.315** (0.144)
Complementary assets	0.287 (0.326)	−0.335** (0.113)
Log business unit employees	−0.064 (0.065)	0.068** (0.021)
Patent effectiveness × Complementary assets	−0.868 (0.849)	0.543* (0.255)
No. of technological rivals	0.006 (0.012)	−0.018** (0.005)
% basic R&D	1.948 (1.853)	−0.422 (0.636)
Importance of medical/health science	0.231 (0.215)	−0.066 (0.061)
Importance of basic science	0.214 (0.203)	−0.034 (0.048)
Parent firm is global	−0.304 (0.310)	0.249* (0.106)
Parent firm is foreign	−0.15 (0.248)	0.193 (0.119)
Parent firm is public	−0.105 (0.201)	0.267** (0.086)
Sigma (σ_η)	0.943 (0.911)	
Industry fixed effects (7)	*YES*	*YES*
N = 757		

Notes:
1. The adjusted R^2 is 0.18 and 0.43 for the licensing and patenting equations, respectively.
2. Standard errors in parentheses. **, *: Significantly different than zero at the 0.01, and 0.05 confidence levels.