International Technology Diffusion: Theory and Measurement

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Motivation

- Countries that were slow to adopt or imitate outside ideas experienced slower growth. Example: Britain vs. Germany, US, Japan
- Why does research occur in different countries?
- How does research give rise to innovations?
- Where do these innovations generate increase in productivity?

Model Features: Data

DATA

	Germany	France	U.K.	Japan	U.S.
Adjusted research employment (thousands)	97	41	74	289	477
Workforce (millions)	29	25	28	61	120
Relative output per hour in manufacturing	0.86	0.91	0.66	0.78	1
Patent applications seeking protection in			By inventors from		
Germany	43342	5130	4739	14553	18849
France	13428	15365	4389	10859	17627
U.K.	13029	4961	24176	12984	19720
Japan	7487	2685	2811	65128	17505
U.S.	13159	5178	6418	32829	83333
Adjusted GDP ($ billions)	1751	1299	921	3662	5876
Application costs ($) to patent in			Paid by inventors from		
Germany	1066	1066	1066	3066	1066
France	992	992	992	3042	992
U.K.	1200	1200	1200	4020	1200
Japan	4772	4772	4772	9590	4772
U.S.	3390	3440	1390	4210	1390

Overview: What will this paper do?

- Present a model of world growth driven by technological diffusion
- Characterize steady state as balanced growth path
- Fit model to data after estimating some key parameters. It will predict for 5 countries:

  -Number of researchers

  -Productivity relative to US

  -Direction of patents for protection in each of the 5 countries (5 x 5 matrix)
- Counterfactual experiments - patterns of diffusion (autarky vs. borderless) and rigor of patent protection

Model: Production

Final good

- Final goods Y_{nt} produced in country $n = 1, ..N$, at time t produced with Cobb-Douglas technology, from intermediate goods $X_{nt}(j)$ of different quality $Z_{nt}(j)$

$$\ln(\frac{Y_{nt}}{J}) = J^{-1} \int_0^J \ln\left[Z_{nt}(j) X_{nt}(j)\right] dj$$

Intermediate goods

$$X(j) = K(j)^{\phi} L(j)^{1-\phi}$$

where $\phi \in [0, 1]$ =capital elasticity

Assumptions:

-
    - Output is homogeneous and tradable across countries
    - Inputs are nontraded
    - Range of inputs, J, is fixed over time
    - capital elasticity same across inputs, countries, and time

Model: Ideas

- Idea: a unit of research output
- research input: s_{ti} (share of labor force in research)
- ideas production/arrival rate: $\alpha_{it} s_{it}^{\beta} L_{it}$
  - α_{it} =overall productivity of research effort in country i at time t
  - β = rate at which research productivity declines as less talented workers become researchers
  - L_{it} =labor force in country i at time t
- 3 dimensions – Quality, Adoption, Diffusion Lag

Quality of Idea

- $Q \sim F(Q)$
- Assume Pareto distribution. So $F(Q)$ =Prob($x < Q$)$= 1 - Q^{-\theta}$
- An idea of quality q is adopted if its quality is higher than current state of the art z, thus:

$$\text{Prob of adopting idea} = P(q > z) = z^{-\theta}$$

Diffusion Lag of Idea

- Ideas diffuse from country i to country n at rate ϵ_{in}

$$\epsilon_{in} = \text{speed of diffusion from country i to country n}$$

- Assume that diffusion lags, τ_{in}, follows exponetial distribution

$$\tau_{in} \sim \text{exponential } (\epsilon_{in})$$

- This means that the probability that an idea invented at country i take less than periods x to diffuse to country n is

$$\Pr(\tau_{in} \leq x) = 1 - e^{-\epsilon_{in} x}$$

- Mean diffusion time is

$$\text{average time it takes to diffuse from i to n} = \frac{1}{\epsilon_{in}}$$

Idea Adoption

- An idea is diffused doesn't mean it is adopted by the recipient country
- An idea of quality q is adopted/used only if:

$$q > Z(j)$$

  The idea's quality is higher than the current state of the art for producing that intermediate good j

Technological Frontier

- Define the highest quality for each intermediate good j in country n at time t as, $Z_{nt}(j)$—the "State of the Art"
- "The State of the Art" across all intermediate goods in that country form that technological frontier
- The technological frontier in country n at time t is summarized by the cumulative distribution of the state of the arts
- Fraction of inputs whose state of the art is below z:

$$Z_{nt}(j) \sim H_n(z; t)$$

Obtaining the Technological Frontier

Step (1): Dynamics of diffusion of ideas into country n

- Define the stock of diffused ideas at country n $\mu_{nt} = \int_{-\infty}^{t} \dot{\mu}_{ns} ds$
- $\dot{\mu}$ is the stochastic rate at which ideas diffuse to country n from research done all over the world and domestically:

$$\dot{\mu}_{nt} = J^{-1} \sum_{i=1}^{N} \int_{-\infty}^{t} \underbrace{\epsilon_{in} e^{-\epsilon_{in}(t-s)}}_{\substack{\text{fraction diffused to} \\ \text{country n in remaining time}}} \cdot \underbrace{\alpha_{is} s_{is}^{\beta} L_{is}}_{\substack{\text{\# of ideas produced} \\ \text{at country i at time s}}} ds$$

- The rate of adopting diffused ideas:

$$\dot{\mu} \times \text{Prob}(q > z) = \dot{\mu} \cdot z^{-\theta}$$

- Now we can solve for $H(z;t)$

- Let x =time adopting new ideas
- By the memoryless property of the exponential distribution

$$\begin{aligned} P(x < t + s) &= P(x < t) \cdot P(x < s) \\ H_n(z; t + dt) &= H_n(z; t) \cdot H_n(z; dt) \end{aligned}$$

- $H_n(z; dt)$ can be interpreted as the probability of having no new adoption within the period dt

$$\begin{aligned} H_n(z; dt) &= P(\text{no adoption in } dt) \\ &= P(x > dt) \\ &= e^{-\dot{\mu} z^{-\theta} dt} \end{aligned}$$

- Rewrite, giving us a differential equation.

$$H_n(z; t + dt) = H_n(z; t) \cdot e^{-\dot{\mu} z^{-\theta} dt}$$

- Solve the differential equation, with two boundary conditions

$$
\begin{aligned}
\lim_{s \to -\infty} H_n(z;s) &= 1 \qquad \forall z \geq 1 \\
\lim_{s \to -\infty} \mu_{ns} &= 0
\end{aligned}
$$

- Gives

$$H_n(z;t) = e^{\mu_{tn} z^{-\theta}}$$

Production

- Now we can rewrite the production technology

$$Y_{nt} = A_{nt} K_{nt}^{\phi} \left[L_{nt} (1 - s_{nt}) \right]^{1-\phi}$$

where the TFP is the geometric mean of the technological frontier

$$A_{nt} = \exp \left\{ \int_1^{\infty} \ln(z) dH_n (z; t) \right\}$$

- EK shows that as μ_{nt} becomes large, TFP is proportional to growth in the stock of ideas diffused to the country

$$A_{nt} = e^{\Psi/\theta} \mu_{nt}^{1/\theta}$$

Market Structure

- All producers of intermediates in a country face the same w and cost of capital r'. So they have the same unit cost

$$c = \left(\frac{r'}{\phi}\right)^{\phi} \left(\frac{w}{1-\phi}\right)^{1-\phi}$$

- Bertrand Competition - new idea compete against the previous state of the art
- Owner of the invention charges the highest price at which it remains the only seller of that input

Implication of Market Structure for Input Prices

- Think about cost per quality. With Bertrand Competition, prices driven down to perfect competition.
- Equating the cost per quality of the previous state of the art and the counter part with the new quality

$$\frac{c}{z} = \frac{p_q}{q}$$

- Thus prices for inputs differ across inputs, depending on the "step of invention"

$$p(j) = \left(\frac{q(j)}{z(j)}\right) c$$

Value of an Idea

- An idea has positive value only if $q \geq z$
- ideas face a hazard rate of ι of being imitated, in which case it loses all of its value
- The expected discounted value of the right to use an idea from country i of quality q in country n, given that the previous state of the art z

$$V_{int}(z, q) = \int_0^\infty \pi_{n,t+s}(z, q) e^{-rs} e^{-\iota s} \left(1 - e^{-\epsilon_{in} s}\right) e^{-\left(\mu_{nt+s} - \mu_{nt}\right) q^{-\theta}} ds$$

Value of an Idea

- Profits are

$$\pi_{n,t+s}(z,q) = \frac{Y}{J}\left[1 - \frac{z}{q}\right]$$

because

$$\begin{aligned} X(j) &= \frac{P \cdot Y}{J \cdot P(j)} = \frac{Y}{J \cdot P(j)} \\ \text{and } \pi &= P(j)X(j) - cX(j) \\ &= \frac{Y}{J} - \frac{Yz}{Jq} \\ &= \frac{Y}{J}\left[1 - \frac{z}{q}\right] \end{aligned}$$

Value of an Idea

- Assumption: at the time of invention research knows the quality of his idea, but not the quality of the competing input in any country
- The expected value of an idea of quality q from country i in country n,

$$V_{int}(q) = \int_1^q V_{int}(z, q) dh_n(z; t)$$

Decision to Patent

- Having a patent decreases the hazard rate of imitation

$$\iota^{pat} < \iota^{not}$$

- The cost of the patent for inventor in country i in country n should equal to

$$V_{int}^{pat}(q) - V_{int}^{not}(q) = f_{int}$$

- The equation above determines the threshold $\overline{q}_{int}$ above which inventors in country i patent in country n
- The rate inventors in country i patent in country n is

$$P_{int} = \underbrace{\alpha_{it} s_{it}^{\beta} L_{it}}_{\text{ideas produced in i}} \cdot \underbrace{\left(\overline{q}_{int}\right)^{-\theta}}_{\text{probability of } q > \overline{q}}$$

Value of an Idea: Return to R&D

- Value of an idea: $\max\left\{V_{int}^{pat}(q) - f_{int}, V_{int}^{not}(q)\right\}$
- Before the quality is known, the expected value of an idea for country i in country n is

$$V_{int} = \int_1^{\overline{q}_{int}} V_{int}^{not}(q)\,dF(q) + \int_{\overline{q}_{int}}^{\infty} V_{int}^{pat}(q)\,dF(q) - f_{int}(\overline{q}_{int})^{-\theta}$$

- Summing across countries n, the expected return to an idea of unknown quality is

$$V_{it} = \sum_{n=1}^{N} V_{int}$$

Equilibrium Number of Researchers

Equalization of wages between the research and production sector in country i gives the equilibrium s_{it}, the share of labor force who are researchers

$$\alpha_{it}\beta V_{it}s_{it}^{\beta-1} = w_{it}$$

Technology and Income

- Aggregate output in country i at time t is

$$Y_{it} = \frac{\kappa_1(\theta)}{\kappa_2(\theta)} A_{it} k_{it}^{\phi} L_{it} (1 - s_{it})$$

- Cobb Douglas assumption implies that the capital to labor ratio k is

$$k_{it} = \frac{\phi}{1-\phi} \frac{w_{it}}{r'}$$

- Rewrite the aggregate output in terms of wage and cost of capital

$$Y_{it} = \frac{1}{\kappa_2(\theta)} \left[\kappa_1(\theta) A_{it} \left(\frac{\phi}{r'} \right)^{\phi} \right]^{\frac{1}{1-\phi}} L_{it} (1 - s_{it})$$

Wages

- Wage for production workers is

$$w_{it} = (1 - \phi)\kappa_1 (\theta) A_{it} k_{it}^{\phi}$$

Rewrite wages in terms of cost of capital

$$w_{it} = (1 - \phi) \left[\kappa_1 (\theta) A_{it} \left(\frac{\phi}{r'} \right)^{\phi} \right]^{\frac{1}{1-\phi}}$$

Constant Growth Path

We want μ_{nt} to grow at a constant rate - g.

- Additional Assumptions
  - Workforce grows at rate g_L.
  - The relative productivity of researchers is proportional to the relative level of technology in their country and to the world stock of ideas:

$$\alpha_{it} = \alpha \left(\frac{\mu_{it}}{\overline{\mu}_t} \right) \overline{\mu}_t^{\gamma}$$

  - Patenting costs are a constant proportion of output $\Rightarrow f_{int} = f_{in} Y_{it}$
  - Interest rate (r) and cost of capital (r') are constant.

Two Scenarios

Full endogenous growth

- $g_L = 0$ and $\gamma = 1$ as in Romer(1990)

$$Y = K^{\alpha} (AL_Y)^{1-\alpha}$$
$$\dot{A} = \delta L_A A$$

Semi-endogenous growth

- $g_L > 0$ and $\gamma < 1$ as in Jones(1995)

$$Y = K^{\alpha} (AL_Y)^{1-\alpha}$$
$$\dot{A} = \delta L_A A^{\phi},\ \phi < 1$$

Note that if $g_L > 0$ and $\gamma \geq 1$ then we have explosive behaviour.

Features of Growth Path (i)

- Fraction of researchers (s_i) is constant in each country.
- Patenting is constant in each country.
- TFP grows at rate $\frac{g}{\theta}$.
- Wage rate grows at rate $\frac{g}{\theta(1-\theta)}$.

Features of Growth Path (ii)

- Output grows at rate $g_y = \frac{g}{\theta(1-\theta)} + g_L$.
- Mean lag between invention in country i and adoption in country n is $\frac{1}{\epsilon_{ni}+g}$ (conditional on it being adapted).
- Country n adopts fraction $\frac{\epsilon_{ni}}{\epsilon_{ni}+g}$ of the ideas from country i that it would have immediately accepted if they arrived immediately.
- $\tilde{L}_i \equiv L_{it}\bar{\mu}_t^{\gamma-1}$ is constant in either the full endogenous or semi-endogenous case ($g = \frac{g_L}{1-\gamma}$).

Steady State Relative Productivities and Growth

With a constant s_i the stock of ideas in each country grows at rate g:

$$g = \frac{\dot{\mu}_i}{\mu_i} = \frac{\alpha}{J} \sum_{n=1}^{N} \frac{\epsilon_{in}}{\epsilon_{in} + g} \frac{\mu_n}{\mu_i} s_n^{\beta} \tilde{L}_n$$

Three effects on growth:

1. Generation of ideas in n: $\alpha \mu_{nt} s_n^{\beta} \tilde{L}_n$
2. Fraction of ideas useful in country i when invented: $\frac{1}{\mu_{it}}$
3. Fraction of ideas adopted which where useful when invented: $\frac{\epsilon_{in}}{\epsilon_{in}+g}$

Steady State Relative Productivities and Growth

To solve for g we must solve a system of N equations for g:

Define $\mu \equiv \left[\frac{\mu_{1t}}{\mu_{Nt}}, \frac{\mu_{2t}}{\mu_{Nt}}, ..., \frac{\mu_{N-1t}}{\mu_{Nt}}, 1\right]$

System can be represented as:

$$\mu g = \Delta(g)\mu$$

Where:

$$\Delta(g) = \begin{bmatrix} \frac{\epsilon_{11}}{\epsilon_1 + g}\frac{\alpha}{J}s_1^{\beta}\tilde{L}_1 & \cdots & \frac{\epsilon_{1N}}{\epsilon_{1N} + g}\frac{\alpha}{J}s_N^{\beta}\tilde{L}_N \\ \vdots & \ddots & \vdots \\ \frac{\epsilon_{N1}}{\epsilon_{N1} + g}\frac{\alpha}{J}s_1^{\beta}\tilde{L}_1 & \cdots & \frac{\epsilon_{NN}}{\epsilon_{NN} + g}\frac{\alpha}{J}s_N^{\beta}\tilde{L}_N \end{bmatrix}$$

Recover g and μ_{nt}.

Steady State Relative Productivities and Growth

Using solution to μ_{it} calculate ratio of TFPs:

$$\frac{A_{it}}{A_{Nt}} = \left(\frac{\mu_{it}}{\mu_{Nt}}\right)^{\frac{1}{\theta}}$$

Steady State Patenting

We have already seen that $\bar{q}_{int}$ defines the threshold from which it is worth patenting.

To ensure a steady state we require that the ratio of patented ideas to adpoted ideas be constant and given by:

$$\bar{b}_{in} = \mu_{it} \left(\bar{q}_{int}\right)^{-\theta}$$

Patenting threshold is only affected by:

- adoption lag - ϵ_{it}
- patent protection - ι_{in}^{pat} and ι_{in}^{not}
- cost of patenting f_{in}

Steady State Patenting

Using rate of patented ideas, the patenting of ideas from country i in country n is given by:

$$P_{in} = \alpha s_n^{\beta} \tilde{L}_n \frac{\mu_n}{\mu_i} \bar{b}_{in}$$

Steady State Labor Market Equilibrium

Using the model we can derive the following equation:

$$\alpha\beta s_n^{\beta-1}\sum_{i=1}^{N} v_{in}\tilde{L}_i\left(1-s_i\right)\left(\frac{\mu_i}{\mu_n}\right)^{\frac{1-\theta+\phi\theta}{\theta(1-\phi)}}=\left(1-\phi\right)\kappa_2\left(\theta\right)$$

Where $v_{in}\equiv\mu_{it}\frac{V_{int}}{Y_{it}}$, which is constant.

Data

- Data for the five leading research nations in the OECD $\rightarrow$ France, Germany, Japan, UK and US
- Researchers employed in 1988 and R&D expenditure - OECD (1991)
- Workforce - Summer and Heston (1991)
- Labor productivity in 1990 - van Ark (1996)
- Patent applications (1988-1990 average) - WIPO (1990)
- Patent costs - Helfgott (1993)

Assume that the countries are in steady-state at the end of 1980s

Model is:

$$Y = G\left(\Theta, X\right)$$

Where

$$Y = \begin{bmatrix} \text{Productivity Growth} \\ \text{Relative Productivity} \\ \text{Research} \\ \text{Patents} \end{bmatrix},$$

$$X = \begin{bmatrix} \text{Workforces} \\ \text{Patenting Costs relative to GDP} \end{bmatrix}$$

$$\Theta = \left(\theta, \alpha, \beta, \iota_{in}^{pat}, \iota_{in}^{not}, \epsilon_{in}, r, g_L, \gamma, \phi\right)$$

Estimation

Fix parameters (i)

Imitation rates - $\iota_{in}^{pat}, \iota_{in}^{not}$

Assume all patent systems (and imitation rates) are the same $\Rightarrow$ $\iota_{D}^{pat}, \iota_{F}^{pat}, \iota_{D}^{not}$ and ι_{F}^{not}

ι_{F}^{not}	0.25	Mansfield and Romeo (1980)
ι_{D}^{pat}	0.23	Mansfield, Schwartz and Wagner (1981)
ι_{D}^{pat}	0.415	Mansfield, Schwartz and Wagner (1981)

Diffusion rates - ϵ_{ni}

Define:

$$\epsilon_{in} = \epsilon_{i.}\epsilon_{.n}\epsilon_{D}$$

- if $i \neq n \, \epsilon N$ then $\epsilon_D = 1$ and $\epsilon_{N.} = 0.1$.
- Adoption rate in US is from 1.2 to 2.5 years $\Rightarrow 2.5 = \frac{1}{\epsilon_{US.}\epsilon_{.US}\epsilon_{D}+g}$

Other Restrictions

r	0.07	Long run real return in US stock market
ϕ	0.3	Capital elasticity from Lysko (1995)

- α chosen so that model gives $g_A = 0.018$ from Lysko (1995) - average from 1979-1990 of the mean of TFP growth in France Germany and US.
- Endogenous case: $g_L = 0$ and $\gamma = 1$
- Semiendogenous case: set γ so that $g_A = \frac{g_L}{(1-\gamma)\theta} = 0.018$ with $g_L = 0.02$.

With parameter restrictions and after applying logs the model is:

$$y = g\left(\Theta, X\right) + u$$

Where

$$\begin{aligned} y &= \begin{bmatrix} \text{Relative Productivity - } \ln\left(\frac{A_i}{A_N}\right) \\ \text{Research - } \ln\left(s_i L_i\right) \\ \text{Patents - } P_{ij} \end{bmatrix}, \\ X &= \begin{bmatrix} \text{Workforces - } L_i \\ \text{Patenting Costs relative to GDP - } f_{ij} \end{bmatrix} \end{aligned}$$

Estimator: $\left[y - g\left(\hat{\Theta}, X\right)\right]' \Omega \left[y - g\left(\hat{\Theta}, X\right)\right]$

Results

Model Fit

	Germany		France		U.K.		Japan		U.S.	
Researchers (thousands)	97	(110)	41	(40)	74	(68)	289	(329)	477	(425)
Productivity (relative to U.S.)	0.90	(0.91)	0.94	(0.94)	0.75	(0.75)	0.84	(0.85)	1	
Patents (thousands) for protection in					By inventors from					
Germany	43	(27)	5	(6)	5	(6)	15	(15)	19	(36)
France	13	(10)	15	(19)	4	(6)	11	(13)	18	(32)
U.K.	13	(9)	5	(4)	24	(20)	13	(9)	20	(17)
Japan	7	(8)	3	(4)	3	(4)	65	(45)	18	(20)
U.S.	13	(8)	5	(4)	6	(6)	33	(16)	83	(119)

Note: Actual values with predicted values in parentheses. Here and in subsequent tables productivity measures reflect total factor productivity assuming a constant capital-output ratio and a capital share of 0.3.

Results

PARAMETER VALUES

Definition	Symbol	Parameter Value: Endogenous	Parameter Value: Semiendogenous
Population growth	g_L	0.00	0.02
Parameter of research spillover	γ	1	0.40
Parameter of search distribution	θ	1.87 (1.06)	1.85 (1.05)
Parameter of talent distribution	β	0.18 (0.02)	0.16 (0.02)
Number of inputs (millions)	J	1.11 (0.62)	1.12 (0.62)
Imitation rates			
If not patented at home	ι_D^{not}	0.415	0.415
If not patented abroad	ι_F^{not}	0.250	0.250
If patented at home	ι_D^{pat}	0.230	0.230
If patented abroad	ι_F^{pat}	0.244 (0.002)	0.245 (0.002)
Diffusion factor from			
Germany	$\epsilon_{.1}$	0.93 (0.67)	0.93 (0.67)
France	$\epsilon_{.2}$	0.28 (0.23)	0.28 (0.22)
U.K.	$\epsilon_{.3}$	0.58 (0.56)	0.56 (0.54)
Japan	$\epsilon_{.4}$	1.17 (1.10)	1.20 (1.14)
U.S.	$\epsilon_{.5}$	0.21 (0.20)	0.21 (0.20)
Diffusion factor to			
Germany	$\epsilon_{1.}$	0.19 (0.13)	0.20 (0.13)
France	$\epsilon_{2.}$	0.22 (0.14)	0.22 (0.14)
U.K.	$\epsilon_{3.}$	0.07 (0.05)	0.07 (0.05)
Japan	$\epsilon_{4.}$	0.11 (0.08)	0.12 (0.08)
U.S.	$\epsilon_{5.}$	0.10	0.10
Diffusion factor domestic	ϵ_D	17.7	17.8

NOTE: Numbers in parentheses are approximate standard errors. Parameters without standard errors have been calibrated based on outside sources of information (described in the text). We parameterize the diffusion rate to destination n from source i as $\epsilon_{ni} = \epsilon_{n.}\epsilon_{.i}\epsilon_D$, where ϵ_D takes on the value 1 if $n \neq i$ and the value in the last row of the table if $n = i$. The value of $\epsilon_{5.} = 0.1$ is simply a normalization.

Speed of Diffusion

- From our calculations $g \simeq 3.35\%$ in the endogenous case

Speed of Diffusion

	Research Performed in				
Diffusion to	Germany	France	UK	Japan	US
Germany	3.1280	0.0532	0.1102	0.2223	0.0399
France	0.2046	1.0903	0.1276	0.2574	0.0462
UK	0.0651	0.0196	0.7186	0.0819	0.0147
Japan	0.1023	0.0308	0.0638	2.2780	0.0231
US	0.0930	0.0280	0.0580	0.1170	0.0399

- Ideas diffuse quickly in Germany and Japan but slowly in the US (?)
- Japanese and German ideas diffuse more rapidly while US ideas diffuse more slowly
- Ideas diffuse more rapidly to France

Results

- Percentage of adopted ideas that would have been initially adopted: $\frac{\epsilon_{in}}{\epsilon_{in}+g}$

ADOPTION PERCENTAGES

Fraction of Potentially Useful Ideas that Are Ever Adopted in	Originating from Research Performed in				
	Germany	France	U.K.	Japan	U.S.
Germany	0.99 (0.01)	0.62 (0.14)	0.77 (0.07)	0.67 (0.07)	0.54 (0.16)
France	0.86 (0.07)	0.97 (0.03)	0.79 (0.07)	0.88 (0.06)	0.57 (0.15)
U.K.	0.65 (0.18)	0.37 (0.18)	0.95 (0.05)	0.70 (0.14)	0.30 (0.17)
Japan	0.76 (0.13)	0.49 (0.17)	0.66 (0.10)	0.99 (0.02)	0.41 (0.17)
U.S.	0.73 (0.14)	0.46 (0.19)	0.63 (0.17)	0.78 (0.14)	0.92 (0.05)

NOTE: The element in row n and column i is $\epsilon_{ni}/(\epsilon_{ni} + g)$, which in steady state has the interpretation given in the table. Numbers in parentheses are approximate standard errors.

- High adoption percentage of domestic ideas in each country
- High adoption percentage of German and Japanese ideas and lower adoption percentage of US ideas.

Growth Decomposition

Using equation that separated growth into several sources we can find the importance of each country in affecting growth

Growth Decomposition

Fraction of Productivity Growth in	Due to Research Performed in				
	Germany	France	U.K.	Japan	U.S.
Germany	0.16 (0.02)	0.08 (0.01)	0.07 (0.01)	0.27 (0.02)	0.42 (0.04)
France	0.13 (0.01)	0.11 (0.02)	0.07 (0.01)	0.26 (0.02)	0.42 (0.04)
U.K.	0.15 (0.02)	0.07 (0.01)	0.13 (0.02)	0.32 (0.04)	0.33 (0.06)
Japan	0.14 (0.02)	0.07 (0.01)	0.07 (0.01)	0.35 (0.05)	0.36 (0.05)
U.S.	0.10 (0.01)	0.05 (0.02)	0.05 (0.01)	0.20 (0.03)	0.60 (0.06)

Note: Rows may not sum to 1 due to rounding. Numbers in parentheses are approximate standard errors.

US and Japanese research contribute significantly to the growth in all countries.

Counterfactuals

Experiments with the Rate of Diffusion

	Baseline		Technological Isolation		Borderless Diffusion	
	Endog.	Semi	Endog.	Semi	Endog.	Semi
Productivity growth:	0.018	0.018	0.011	0.018	0.028	0.018
U.S. productivity level:	1.00	1.00	1.00	0.67	1.00	1.41
Productivity (per U.S.)						
Germany	0.91	0.92	3.20	2.09	1.02	1.01
France	0.94	0.94	3.25	2.15	1.02	1.02
U.K.	0.75	0.75	2.94	1.87	0.98	0.99
Japan	0.85	0.85	3.13	2.05	1.01	1.00
Research intensity						
Germany	0.0037	0.0037	0.0025	0.0040	0.0115	0.0073
France	0.0016	0.0016	0.0012	0.0020	0.0081	0.0053
U.K.	0.0025	0.0025	0.0018	0.0029	0.0101	0.0065
Japan	0.0054	0.0054	0.0039	0.0063	0.0119	0.0075
U.S.	0.0035	0.0036	0.0030	0.0049	0.0071	0.0047

Counterfactuals

EXPERIMENTS WITH THE STRENGTH OF PATENT PROTECTION

	Baseline		No IPP		Perfect IPP	
	Endog.	Semi	Endog.	Semi	Endog.	Semi
Productivity growth:	0.0180	0.0180	0.0168	0.0180	0.0248	0.0180
U.S. productivity level:	1.00	1.00	1.00	0.94	1.00	1.41
Productivity (per U.S.)						
Germany	0.91	0.92	0.93	0.92	0.89	0.92
France	0.94	0.94	0.95	0.95	0.92	0.94
U.K.	0.75	0.75	0.77	0.76	0.71	0.75
Japan	0.85	0.85	0.87	0.86	0.82	0.85
Research intensity						
Germany	0.0037	0.0037	0.0030	0.0032	0.0399	0.0443
France	0.0016	0.0016	0.0011	0.0012	0.0207	0.0254
U.K.	0.0025	0.0025	0.0019	0.0021	0.0298	0.0348
Japan	0.0054	0.0054	0.0039	0.0042	0.0462	0.0491
U.S.	0.0035	0.0036	0.0017	0.0018	0.0340	0.0373