Growth, Trade and Patents

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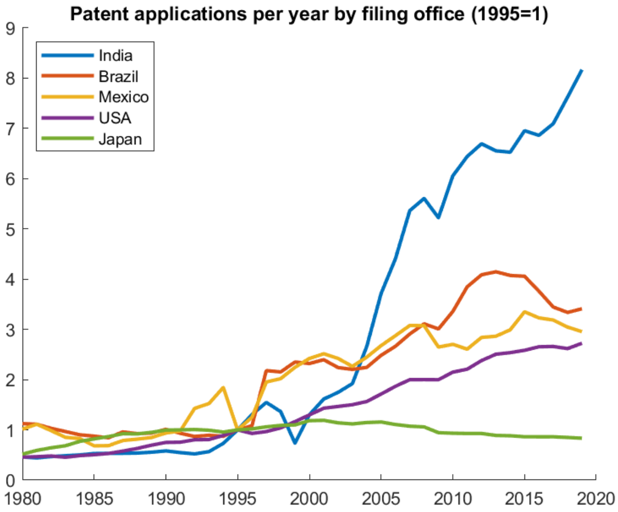
Motivation: trade agreements and innovation

- After decades of tariff reductions, trade negotiations now largely revolve around non-tariff issues
- IPR protection is a particularly contentious non-tariff issue:
  - Many controversies: Covid-19 vaccines, China-US trade war, TPP/CPTPP, HIV/AIDS drugs, ...
- Ultimately, these controversies can all be linked to the Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement;
  - TRIPS imposes minimum IPR standards on all WTO members and provides for their enforcement through trade sanctions.
  - TRIPS pushed developing countries to adopt IPR systems closer to those of developed countries.
  - A common suspicion is that this benefited rich countries at the expense of poor countries.

Welfare effects of IPR?

- This raises a number of questions:
  - What were the welfare consequences of IPR rights in general and TRIPS in particular?
    - In the short-run versus the long-run, for developed versus developing countries, etc.
  - How close to a "first-best" world are we? How close to a "Nash" equilibrium are we?
  - What would be the welfare consequences of further IPR harmonization?
- To answer these questions, one needs a quantitative model of trade, growth and patenting.
  - Goal of this paper: providing such a model.
  - We calibrate it to the world economy.
  - And use it to answer some of these questions.

Patenting in developed vs developing countries



Preview

- Expanding variety growth model where innovators introduce new products.
  - Initially, they are monopolists but if they get imitated, other producers (perhaps in other countries) can produce the variety.
  - Patents allow to maintain monopoly rights for longer: only high quality innovations will be patented.
- 2 types of goods:
  - Some produced monopolistically by the inventor.
  - Some produced competitively as in Eaton Kortum (2002).
- Model highlights trade-offs involved with patenting protection:
  - Patents lead to higher prices in the short-run (monopoly mark-up + sourcing distortion)
  - Patents incentivize innovation (at home and abroad)
  - (Extension: patents enable consumers' access to some products).

Literature review

- Grossman and Lai (2004) analyze cooperative and non-cooperative patent policies in a simple model.
  - Emphasize the trade-off between more varieties with better patents versus less monopoly distortion but not a quantitative model (e.g no growth).
  - Lai and Yan (2013) bring that paper to the data, but paper suffers from the same issues.
- Eaton and Kortum (1999) develop quantitative model of innovation and patenting. Focus is on FDI, not trade.
- Quantitative analysis of TRIPS
  - McCalman (2001) quantifies impact of patent protection on producer surplus holding innovation constant.
  - Chaudhuri, Goldberg and Jia (2006) study impact of TRIPS on pharmaceutical market in India
  - Jakobsson and Segerstrom (2016) quantify effect of increasing imitation costs in North-South product cycle model without patenting
- Santacreu (2021): regional trade agreements with IP protections, focus is on licensing, no patenting.

Roadmap

1. **Static model and equilibrium**
2. Dynamic model and equilibrium
3. Calibration and Counterfactuals
4. Extensions
5. Conclusion

Set-up and preferences

- Infinite time horizon economy, continuous time.
- N countries, each endowed with a fixed labor supply L_n.
- Each country admits a representative agent with utility:

$$U_{nt} = \int_t^\infty e^{-\rho(\widetilde{t}-t)} \frac{C_{n\widetilde{t}}^{1-1/\gamma}}{1-1/\gamma} d\widetilde{t},$$

  - ρ is the discount rate, γ the elasticity of intertemporal substitution and C_{nt} is aggregate consumption.
  - For simplicity, assume perfect national capital markets (i.e. no intertemporal country trade).

Final good production

- Final good Y_{nt} is non tradeable and a CES aggregate of different varieties:

$$Y_{nt} = \left(\int_0^{M_t} \psi(\omega)^{\frac{1}{\sigma}} c_{nt}(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\frac{\sigma}{\sigma-1}},$$

  - $c_{nt}(\omega)$ is the consumption of variety ω in country n: these varieties are the traded goods;
  - $\psi(\omega)$ is the quality of product ω (independent of the sourcing country);
  - $\sigma > 1$ is the elasticity of substitution.
  - M_t is the measure of an endogenous set of varieties $\mathcal{M}_t$.
    - An increase in M_t will be the source of growth.

- Final good market clearing implies:

$$Y_{nt} = C_{nt} + Z_{Rn} + Z_{An}, \tag{1}$$

  - Z_{Rn} and Z_{An} are R&D and patent spending (specified later).

Variety production

- If country i can produce variety ω, production is given by:

$$y_i(\omega) = z_i(\omega)\, l_i(\omega),$$

  - $y_i(\omega)$ denotes output and $l_i(\omega)$ labor. $z_i(\omega)$ is a country-specific productivity.
  - To sell variety ω to country n, a producer in country i faces iceberg trade cost τ^s_{ni}.

- $z_i(\omega)$ drawn from a country-sector specific Frechet distribution (as in Eaton and Kortum, 2002):

$$F_i(z) = \exp\left(-T_i z^{-\theta}\right). \tag{2}$$

  - T_i is a scale parameter which affects afferage productivity in country i (here institutions, infrastructure, culture but not technology).
  - $\theta > \sigma - 1$ measures (the inverse of) productivity dispersion.

Two types of varieties

- From the perspective of a consumer in country n, 2 types of varieties:
- "Eaton Kortum" varieties: a set $\mathcal{M}_{Cn}$ produced competitively and sourced from the cheapest country;
  - A good produced in country i can be sold competitively in country n at price $p_{ni}(\omega) = \tau_{ni} w_i / z_i(\omega)$.
  - Country n will source the good from the cheapest country.
- "Helpman Krugman" varieties: sets $\mathcal{M}_{Mni}$ produced monopolistically by a firm in country i.
  - A good produced by a monopolist in country i is sold in n at $p_{ni}(\omega) = \frac{\sigma}{\sigma-1} \frac{\tau_{ni} w_i}{z_i(\omega)}$.
  - Two disadvantages for consumers from monopolistic goods:
    - ⋆ Standard mark-up $\sigma / (\sigma - 1)$.
    - ⋆ *Good is not necessarily shipped from the lowest marginal cost country.*
- All goods are sold to all countries (though not necessarily in the same way) so $\left(\bigcup_i \mathcal{M}_{Mni}\right) \cup \mathcal{M}_{Cn} = \mathcal{M}_t$ for all n.

Bilateral trade flows

- In both cases, demand is proportional to $\psi(\omega)$:

$$c_{nt}(\omega) = \psi(\omega) \left(\frac{p_{nt}(\omega)}{P_{nt}} \right)^{-\sigma} Y_{nt},$$

  - $p_{nt}(\omega)$ is the consumer price of ω in country n, P_{nt} is the price index.

- Total bilateral trade flows obey:

$$X_{ni} = \left[\frac{T_i (\tau_{ni} w_i)^{-\theta}}{\Phi_{Cn}} \left(\frac{P_{Cn}}{P_n} \right)^{1-\sigma} + \frac{\Psi_{Mni} T_i^{\frac{\sigma-1}{\theta}} (\tau_{ni} w_i)^{1-\sigma}}{\Phi_{Mn}} \left(\frac{P_{Mn}}{P_n} \right)^{1-\sigma} \right]$$

  - First term reflects EK trade with P_{Cn} the price index on competitive goods and $\Phi_{Cn} \equiv \sum_{j=1}^{N} T_j (\tau_{nj} w_j)^{-\theta}$ a multilateral resistance term;
  - Second term reflects HK trade with P_{Mn} the price index on monopolistic goods, $\Phi_{Mn} \equiv \sum_{j=1}^{N} \Psi_{Mnj} T_i^{\frac{\sigma-1}{\theta}} (\tau_{ni} w_i)^{1-\sigma}$ a multilateral resistance term and $\Psi_{Mni} \equiv \int_{\omega \in \mathcal{M}_{Mni}} \psi(\omega) \, d\omega$ the aggregate quality sold monopolistically.

Trade elasticity

- Trade elasticity reflects the "dual" nature of trade in Eaton-Kortum goods and Helpman-Krugman goods.

$$-\frac{\partial \ln X_{ni}}{\partial \ln \tau_{ni}}\Big|_{\Phi_n, \Phi_{Mn}, Y_n, w_i} = \theta \frac{X_{Cni}}{X_{ni}} + (\sigma - 1)\,\frac{X_{Mni}}{X_{ni}},$$

  - Trade elasticity is between the Helpman-Krugman value $(\sigma - 1)$ and the Eaton-Kortum value (θ).

- As more innovative countries will have a higher share of monopolistic goods, the trade elasticity is smaller for more innovating origin countries.

Roadmap

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Variety's life-cycle (1)

- A firm in a given country i invents variety ω with quality $\psi(\omega)$.
  - Firm decides to patent (or not) *separately* for each country.
  - Firm draws country-technology $z_i(\omega)$.
  - Firm sells the variety to all countries monopolistically (Helpman-Krugman good).
- With Poisson rate ν, the technology diffuses in all countries to a continuum of firms.
  - The technologies $z_j(\omega)$ are drawn.
  - If there is an active patent in country n, good ω is still produced monopolistically in country i.
  - If there is no active patent in country n, good ω is now produced competitively (Eaton-Kortum good).

Variety's life-cycle (2)

- Patents expire at Poisson rate δ_n.
  - If the technology has not yet diffused, good ω is still produced monopolistically.
  - If the technology has already diffused, good ω is now produced competitively.
- Structure captures the fact that patents protect an invention in the country where it is sold.
  - A patent gives local monopoly rights.
  - If an inventor wants to be protected in US + Germany + China, they will need 3 patents.

Innovation and patenting technologies

- An innovation creates $\Psi_t^{\frac{\sigma-2}{\sigma-1}}$ products with the same quality $\psi(\omega)$ and each innovation occurs with probability $\eta_i \left(Z_{Ri}\right)^{-\kappa} \left(\Psi_t\right)^{\frac{\kappa}{\sigma-1}}$
  - η_i represents the productivity of innovation in country i. $\kappa \in (0,1)$ parameterizes the elasticity of innovation.
  - $\psi(\omega)$ drawn from a Pareto distribution $H(\psi) = 1 - \psi^{-k}$ where $k > 1$.
  - Ψ_t is the aggregate quality of all varieties:

$$\Psi_t = \int_0^{M_t} \psi(\omega)\, d\omega = \Psi_{Cn} + \sum_{j=1}^{N} \Psi_{Mnj} \text{ for all } n.$$

    - ★ Ψ_{Cn} is the aggregate quality sold competitively.
- There is free entry in innovation.
- Patenting an invention in country n requires f_n units of the final good in the inventor's country.
  - A patent expires at Poisson rate δ_n.

Value of non-patented innovation

- The economy admits a steady-state where

$$g_{Y_n} = g_{C_n} = \frac{g_\Psi}{\sigma - 1} \text{ for all } n.$$

- A monopolist from country i in market n obtains profits

$$\pi_{ni}(\psi, z) = \psi \frac{(\sigma - 1)^{\sigma - 1}}{\sigma^\sigma} \left(\frac{\tau_{ni} w_i}{z} \right)^{1-\sigma} (P_{nt})^\sigma Y_{nt}.$$

- If a product invented at t_0 is non-patented, its value (before knowing z) for the firm is given by

$$V_{nit_0}^{NP}(\psi) = \psi \int_{t_0}^{\infty} E(\pi_{nit}(1, z)) e^{-\left(\bar{r}_{i,t,t_0} + \nu\right)(t - t_0)} dt.$$

  - $\bar{r}_{i,t,t_0}$ is the average interest rate over the period (t, t_0).

- In steady-state

$$V_{nit_0}^{NP}(\psi) = \frac{\psi E(\pi_{nit_0}(1, z))}{r + (\sigma - 2) g + \nu}.$$

Value of patented innovation

- If the product is patented, its value is given by:

$$V_{nit_0}^{s,P}(\psi) = \psi \int_{t_0}^{\infty} E\left(\pi_{nit}(1,z)\right) e^{-\overline{r}_{i,t,t_0}(t-t_0)} \times \left[e^{-\nu(t-t_0)} + \left(1 - e^{-\nu(t-t_0)}\right) e^{-\delta_n(t-t_0)}\right] dt.$$

  - The firm makes profits even if the tech has diffused in the innovation is still protected.

- In steady-state

$$V_{nit_0}^{s,P}(\psi) = V_{nit_0}^{NP}(\psi) + \psi E\left(\pi_{nit_0}^{s}(1,z)\right) \Delta T_n^s.$$

  - with $\Delta T_n^s = \frac{1}{r+(\sigma-2)g+\zeta+\delta_n} - \frac{1}{r+(\sigma-2)g+\zeta+\nu+\delta_n}$ captures the difference in effective discount rates for patented and non patented innovations.
  - ΔT_n^s decreases in δ_n^s.

Patenting threshold

- We get a threshold of innovation quality ψ^*_{nit}, such that all innovations from i with $\psi > \psi^*_{nit}$ are patented in country n.

$$\psi^*_{nit} = \frac{P_{it} f_n}{(\Psi_t)^{\frac{\sigma-2}{\sigma-1}} \left(V^P_{nit}(1) - V^{NP}_{nit}(1) \right)}.$$

- In steady-state:

$$\psi^*_{ni} = \frac{P_i f_n}{\widehat{\pi}_{ni} \Delta T^s_n}.$$

  - where $\widehat{\pi}_{ni} = (\Psi_t)^{\frac{\sigma-2}{\sigma-1}} E\left(\pi_{nit}(1, z)\right)$ is normalized profits (constant in steady-state).
  - For given $r, g, P_i$and $\widehat{\pi}_{ni}$, the patenting theshold increases with δ_n (worse protection), f_n (more expensive patents) and decreases with ν (more imitation).

Value of innovation and R&D

- The expected value of an innovation in country i before learning $\psi(\omega)$ and $z(\omega)$ is then given by:

$$V_{it} = \frac{1}{k-1} \sum_{n=1}^{N} \left[V_{nit}^{NP}(1)\, k + \left(V_{nit}^{P}(1) - V_{nit}^{NP}(1) \right) \left(\psi_{nit}^{s*} \right)^{1-k} \right]$$

  - where we use that ψ is Pareto distributed.

- Free-entry into innovation implies that:

$$P_{it} = \eta_i Z_{Ri}^{-\kappa} \Psi_t^{1-\frac{1-\kappa}{\sigma-1}} V_{it}.$$

- In steady-state, one gets that R&D efforts obeys:

$$\widehat{Z}_{Ri}^{\kappa} = \frac{\eta_i}{k-1} \sum_{n=1}^{N} \left[\frac{\widehat{\pi}_{ni}}{P_i} \frac{k}{r + (\sigma-2)\, g + \nu} + \left(\psi_{ni}^{*} \right)^{-k} f_n \right].$$

  - where $\widehat{Z}_{Ri} = Z_{Rit} / \left(\Psi_t \right)^{1/(\sigma-1)}$ are (constant) normalized R&D expenditures in steady-state.
  - Everything else given, R&D increases when the share of patented innovation,$\left(\psi_{ni}^{*} \right)^{-k}$, is higher.

Growth

- The growth rate of the economy is then given by

$$g = \frac{1}{\sigma - 1} \sum_{i=1}^{N} \eta_i \frac{k}{k-1} \widehat{Z}_{Ri}^{1-\kappa}$$

  - All R&D expenditures across the world matter for long-run growth.
  - Patenting institution in *each* country matter for innovation and growth in *all* countries.
    - ⋆ but patents are not necessary for growth.

- In steady-state, welfare in country n is

$$U_{n0} = \frac{C_{n0}^{1-\gamma^{-1}}}{\left(1-\gamma^{-1}\right)\left(\rho - g\left(1-\gamma^{-1}\right)\right)}.$$

  - which naturally shows the dynamics vs static welfare trade-offs.

Effect of patenting on growth (1)

$$\frac{\partial \ln g}{\partial \ln \delta_n} = \frac{\text{direct effect} + \text{world profits effect}}{1 + \text{dampening term}}.$$

- The direct effect corresponds to the direct impact of patent regulation in country n on R&D expenditures for all countries i.

$$\begin{aligned} & \text{direct effect} \\ = \quad & -\frac{1-\kappa}{\kappa} k \left(\frac{\delta_n}{r_{NP} - \nu + \delta_n} + \frac{\delta_n}{r_{NP} + \delta_n} \right). \\ & \times \sum_{i=1}^{N} \underbrace{\frac{\eta_i \frac{k}{k-1} Z_{Ri}^{1-\kappa}}{g}}_{\substack{\text{How important} \\ \text{is R\&D in } i}} \quad \underbrace{\frac{\widehat{V}_{nit}^{s}}{\sum_{k=1}^{N} \widehat{V}_{kit}^{s}}}_{\substack{\text{How important} \\ n \text{ is for } i}} \quad \underbrace{\frac{\left(\psi_{ni}^{s*}\right)^{1-k} \Delta T_n}{\frac{k}{r_{NP}} + \left(\psi_{ni}^{*}\right)^{1-k} \Delta T_n}}_{\substack{\text{How important patenting} \\ \text{in } n \text{ is for innovators of}}} \end{aligned}$$

  - $r_{NP} = r + (\sigma - 2)g + \zeta + \nu$ is the effective discount rate for non-patented innovations.

Effect of patenting on growth (2)

- The world profits effect corresponds to the impact of patent regulations on profits relative to innovation costs for all markets and all innovators:

$$\text{world profits effect}$$
$$= \frac{1-\kappa}{\kappa} k \sum_{i=1}^{N} \frac{\eta_i \frac{k}{k-1} Z_{Ri}^{1-\kappa}}{g} \sum_{m=1}^{N} \frac{\widehat{V}_{mit}^{s}}{\sum_{k=1}^{N} \widehat{V}_{kit}^{s}} \left(\frac{\frac{1}{r_{NP}} + (\psi_{mi}^{*})^{1-k} \Delta T_m}{\frac{k}{r_{NP}} + (\psi_{mi}^{*})^{1-k} \Delta T_m} \right) \frac{\partial \ln \frac{\widehat{\pi}_{mi}}{P_i}}{\partial \ln \delta_m}.$$

Effect of monopolies on income (1)

- Real income in country i can be written as $Y_i = \frac{w_i}{P_i} L_i + \Pi_i$.
- Real wages are given by:

$$
\begin{aligned}
\frac{w_i}{P_i} = & \left[\Gamma\left(\frac{\theta+1-\sigma}{\theta}\right)\Psi\right]^{\frac{1}{\sigma-1}} \left(\frac{T_i}{\mu_{CDi}}\right)^{\frac{1}{\theta}} \times \\
& \left[1 - \sum_{j=1}^{N} \frac{\Psi_{Mij}}{\Psi} \left(1 - \frac{\left(\frac{\sigma-1}{\sigma}\right)^{\sigma-1} T_j^{\frac{\sigma-1}{\theta}} \left(\tau_{ij} w_j\right)^{1-\sigma}}{\left(\sum_{k=1}^{N} T_k \left(\tau_{ik} w_k\right)^{-\theta}\right)^{\frac{\sigma-1}{\theta}}}\right)\right]^{\frac{1}{\sigma-1}}
\end{aligned}
$$

  - with $\mu_{CDi} = \frac{T_i w_i^{-\theta}}{\sum_{j=1}^{N} T_j \left(\tau_{ij} w_j\right)^{-\theta}}$. The formula highlights the two sources of losses from monopolistic trade.

Effect of monopolies on income (2)

- Aggregate profits Π_i are:

$$\Pi_i = \frac{1}{\sigma} \sum_n \frac{\Psi_{Mni} T_i^{\frac{\sigma-1}{\theta}} \left(\tau_{ni} w_i\right)^{1-\sigma}}{\left[\begin{array}{c} \sum_{j=1}^{N} \Psi_{Mnj} T_j^{\frac{\sigma-1}{\theta}} \left(\tau_{nj} w_j\right)^{1-\sigma} \\ + \left(\frac{\sigma}{\sigma-1}\right)^{\sigma-1} \Psi_{CDn} \left(\sum_{j=1}^{N} T_j \left(\tau_{nj} w_j\right)^{-\theta}\right)^{\frac{\sigma-1}{\theta}} \end{array} \right]} \frac{P_n}{P_i} Y_n .$$

  - The direct effect of increasing Ψ_{Mni}/Ψ is to increase profits in country i; while increasing Ψ_{Mnj}/Ψ tends to reduce profits.

Taking stock

- Model captures the main trade-off of international patent rights:
  - Stronger patent protection favors long-run growth in own but also other countries;
  - But, stronger patent protection hurts consumers through monopoly distortion ...
  - ... and because goods are not shipped from the cheapest country.
  - Stronger patent protection increases profits in the innovating country.

Roadmap

1. Static model and equilibrium
2. Dynamic model and equilibrium
3. **Calibration and Counterfactuals**
4. Extensions
5. Conclusion

Calibrated model

- Local diffusion
  - Goods diffuse locally before they diffuse internationally, which may be more realistic.
  - Only the local diffusion rate matters for innovation incentives.
- Add intermediate inputs $q_i(\omega)$ in production of varieties:

$$y_i(\omega) = \frac{z_i(\omega)}{\alpha^\alpha (1-\alpha)^{1-\alpha}} l_i(\omega)^\alpha q_i(\omega)^{1-\alpha}.$$

- Allows for unbalanced trade with exogenous trade surpluses / deficits.

Calibration

- To start, calibrate the economy to 2005 (a post-TRIPS world).
  - We will later compare to the pre-TRIPS world.
- Assume 7 countries (US, EU, Japan, China, Brazil, India, and RoW) and 1 sector.
- Take some parameters from the literature:
- Use method of moments to estimate the remaining parameters.

Calibration: parameters (1)

Assigned	Value	Description	Source
ρ	0.02	Discount rate	Acemoglu et al. (2018)
γ	0.5	IES	Acemoglu et al. (2018)
ν	0.15	Local technology diffusion rate	
$\tilde{\nu}$	0.075	Intl. technology diffusion rate	
κ	0.5	R&D function concavity	Jones & Williams (2000)
k	1.5	Pareto shape of quality draws	Hall & Harhoff (2012)
σ	2.9	Elasticity of substitution	Broda & Weinstein (2006)
θ	8.28	Inverse productivity dispersion	Eaton & Kortum (2002)
$1-\alpha$	0.49	Intermediate input share	WIOD
L_n		Labor force by country	World Bank

Calibration: parameters (2)

Estimated	Description	Comments
T_i	Absolute advantage	
τ_{ni}	Iceberg trade costs	
η_i	Research productivity	
δ_n	Patent expiration rate	$\delta_{US} = 0.05$ imposed
f	Patenting cost	US patenting cost is ca. \$17000 (Park 2010)

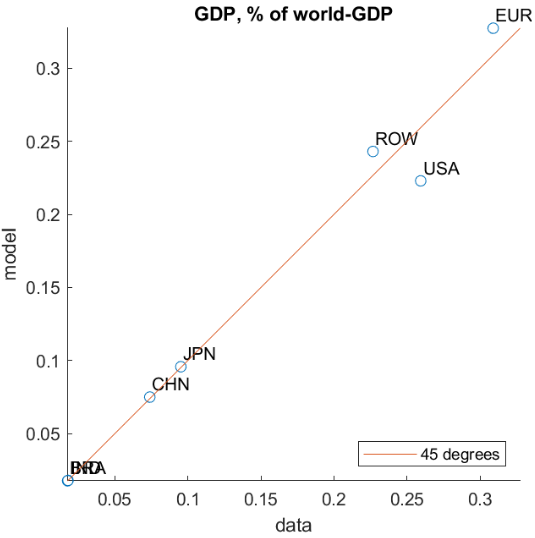
Calibration: moments

Description	Target	Source
Trade flows		WIOD
Trade imbalances		WIOD (assigned)
Patent counts		WIPO, Patstat (EPO)
GDP by country		World Bank
R&D-to-GDP by country		World Bank
Patenting benefit-to-R&D cost ratio in the US	6%	Kogan et al. (2017)
World growth rate 2000-2015	3%	World Bank

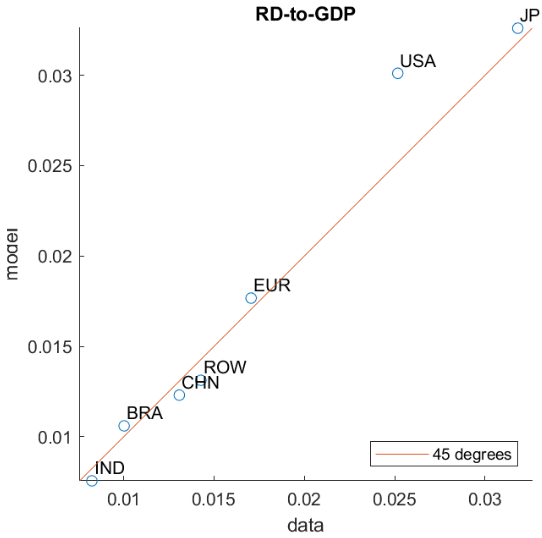
Calibration: model fit (1)

Calibration: model fit (2)

Calibration: model fit (3)



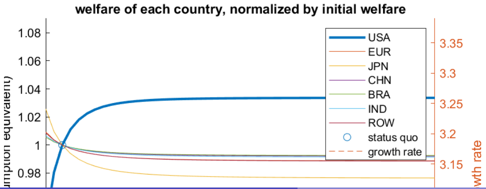
Calibration: model fit (4)



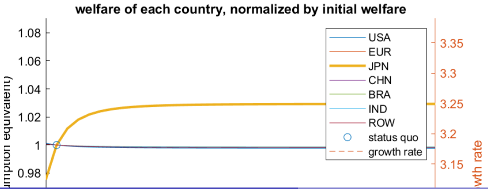
Calibration: patent protection (hazard rate)

Country	Estimated Value
JPN	0.04
USA	0.05
BRA	0.09
EUR	0.10
CHN	0.32
IND	0.52
ROW	0.74

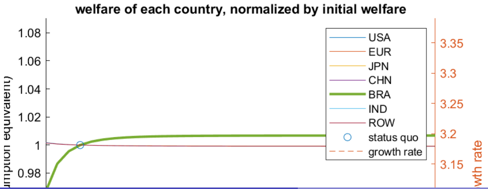
Unilateral optimal patent protection US / EUR



Unilateral optimal patent protection JPN / CHN



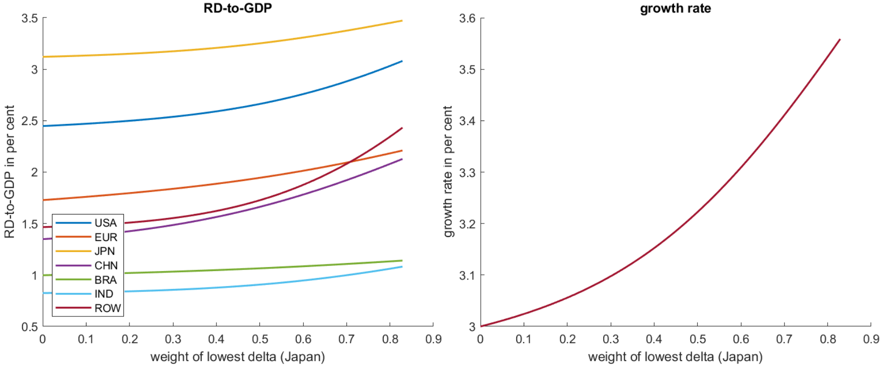
Unilateral optimal patent protection BRA / IND



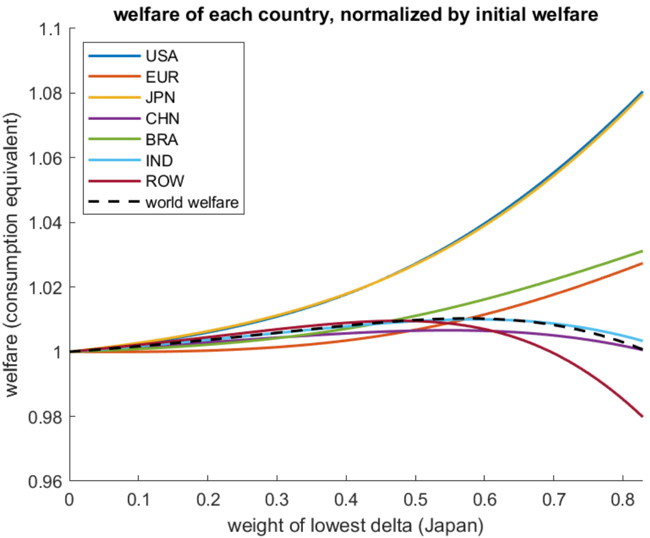
Counterfactual: harmonization (1)

- Change δ_n to $\delta_{JP}^{\omega}\delta_n^{1-\omega}$.

Counterfactual: harmonization (2)

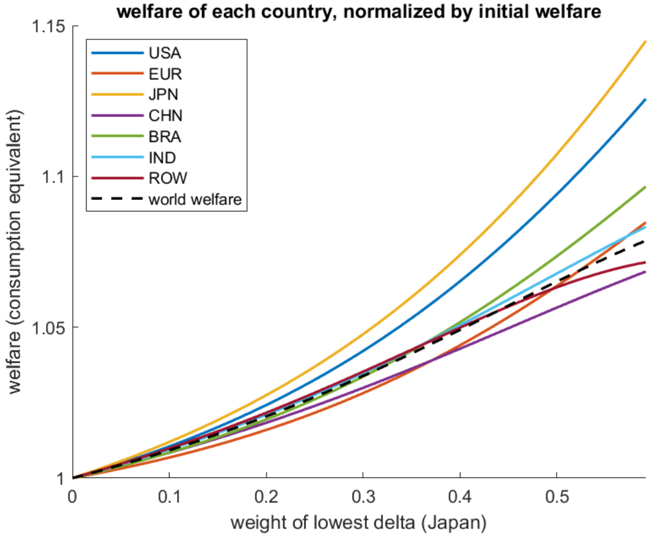


Counterfactual: harmonization (3)



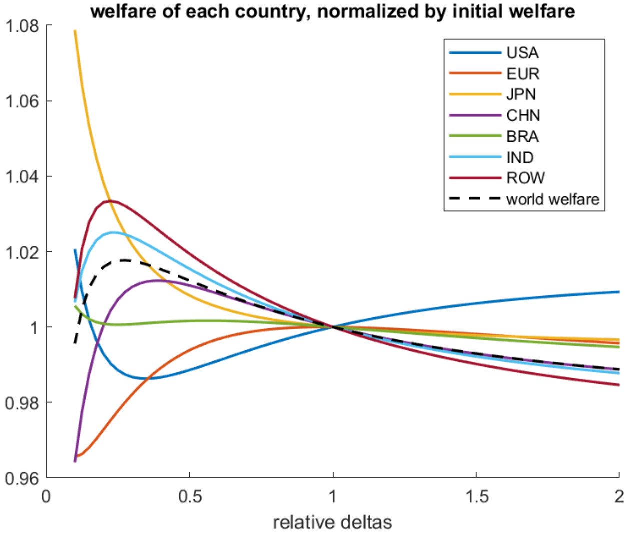
Counterfactual: harmonization under faster diffusion

- Doubling ν



Counterfactual: proportional change

- Multiply all δ_n by a constant



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Further extensions

- Add multiple sectors:
  - Both patenting and trade only affect some sectors.
- Add moments to calibrate f, ν, k.
- Add exporting (one-time) fixed costs for innovating firms;
  - Innovator will enter a market only if she thinks that the keeps her profits for long enough;
  - Some countries may not obtain all goods.
  - This captures the idea that without patenting, firms may not want to sell in certain markets.
- What we don't have (at least yet): bilateral diffusion rate, FDI.

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Conclusion

- Still very early work.
    - But a workhorse model of trade, growth and patenting.
- Goal now is to:
    - Improve the calibration;
    - Run transitional dynamics;
    - Compare current policies with Nash or with the first best;
    - Evaluate the welfare effects of TRIPS.