Innovation, Growth, and Dynamic Gains from Trade

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Motivation

- Arkolakis-Costinot-Rodriguez-Clare (2012; ACR) find that gains from trade (relative to autarky) are quite small in a static model.
- Various angles to re-consider gains from trade:
  - variable markup (Edmond et al. 2015, Arkolakis et al. 2019)
  - input-output linkages (Caliendo and Parro 2015)
  - sectoral heterogeneity (Ossa 2015)
  - .....
- Empirical evidence on the positive relation between trade and economic/productivity growth (Fernandes 2007, Frankel and Romer 1999)
- We explore the role of innovation and dynamic gains from trade. More specifically, we focus on *regime changes in innovation*.

Historical Evolution of Technologies

Regime changes in innovation – *two layers of innovation mechanism*

- upper layer: General Purpose Technology (GPT) – such as internal combustion engines, electricity, digital data processing, macromolecules composition, and semiconductors, ...

- lower layer: process innovation for differentiated products

This Paper

- develops a dynamic general equilibrium model of trade featuring:
  - Advancement of general purpose technology (GPT) driven by R&D in *á la* Aghion-Howitt (1992; AH)
  - endogenous innovation in blue prints for producing differentiated varieties
  - North-South trade with Bernard-Eaton-Jensen-Kortum (2003; BEJK) trade environment
- identifies a novel mechanism for how trade affects innovation and growth.
- conducts a multi-country quantitative analysis on dynamic gains from trade.

Mechanism

- The key mechanism is that trade cost affects the effective market size, which is summarized as a R&D multiplier that captures the incentives for R&D on GPT.
- This mechanism hinges on the North-South trade structure where the North has technology advantage over the South in differentiated products, which induces a large wage gap when trade cost is high.
- Trade liberalization implies that South's labor is sought after more, wage gap is reduced, and the demand from the South also becomes stronger, and these imply that the effective global market size facing North GPT innovators becomes larger.

Literature

On the dynamic gains from trade literature:

- innovation: Hsieh, Klenow and Nath (2019); Impullittiy and Licandro (2017); Bloom-Romer-Terry-Van Reenen (2021).
- social learning: Sampson (2016); Perla-Tonetti-Waugh (2021); Buera and Oberfield (2020).
- capital accumulation: Ravikumar-Santacreu-Sposi (2019)
- trade adjustment dynamics: Alessandria, Choi and Ruhl (2020).

Roadmap and Preview of Main Results

- North-South two-country model
  - illustrates the mechanism of how trade affects long run growth rate.
  - North-South structure based on technology gap in differentiated products is crucial for entailing the positive link between trade and growth.
- Multi-country quantitative model with intermediate goods
  - Substantial total gains from trade: 30.6% (weighted average); North vs South – 32.1% and 30.2%.
  - Substantial dynamic shares: 89.1% (weighted average); North vs South – 83.5% and 90.6%.
  - Dynamic gains larger when trade costs are larger.
  - Dynamic gains amplified by trade in intermediate goods.

Basic Structure

- Two countries of size N_i ($i = 1, 2$): $1 =$ North, $2 =$ South.
- Labor is the only input.
- Differentiated goods produced by firms engaging in Bertrand competition as in BEJK and with GPT monopoly as in AH
- Lifetime utility:

$$U_i = \int_0^\infty Q_{it} e^{-\rho t} dt,$$

with

$$Q_{it} = \left(\int_0^1 (q_{it}(\omega))^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\frac{\sigma}{\sigma-1}}$$

- Production of each good ω requires a blueprint of production process and production workers.
- Each production process requires use of GPT from the North.

Innovations

- The North: There is a unit continuum of GPT innovating firms who hire R_ν effective research labor to entail $\lambda\left(R_\nu\right)$ (Poisson) arrive rate of a new GPT

- When the innovation occurs at time ν, the innovating firm becomes the new GPT monopoly.

- Then at time ν_+ each of the $M_{i\nu}$ entrepreneurs for each good ω draws $\gamma^\nu t_{i0}$ $(\gamma > 1)$ ideas from a Fréchet distribution, $F_i^{\text{draw}}\left(z\right) = e^{-z^{-\theta}}$,
  - t_{i0} is the initial number of ideas per entrepreneur at time 0 $(t_{10} > t_{20})$.
  - The stock of ideas at time ν is $T_{i\nu} = \gamma^\nu M_{i\nu} t_{i0}$.
  - The best idea prevails in the market for each ω.

Innovations

- From $T_{i\nu} = \gamma^{\nu} M_{i\nu} t_{i0}$, the resulting distributions of
  - maximum productivity $F_{i\nu}(z) = e^{-T_{i\nu} z^{-\theta}}, \quad z \geq 0$
  - joint distribution of top two productivities $F_{i\nu}(z_1, z_2) = [1 + T_{i\nu}(z_2^{-\theta} - z_1^{-\theta})] e^{-T_{i\nu} z_2^{-\theta}}$.
- The GPT monopoly and each successful entrepreneur engage in Nash bargaining with the bargaining power of the GPT firm $= \beta \in (0, 1)$

Production and Trade

- Unit cost of supplying consumers in country n by the kth most efficient producers located in i:

$$C_{kni}(\omega) = \left(\frac{w_i}{Z_{ki}(\omega)}\right)\tau_{ni},$$

where $\tau_{ni} = 1$ if $n = i$, $\tau_{ni} = \tau$ if $n \neq i$; $Z_{1i}(\omega)$ and $Z_{2i}(\omega)$ follows $F_{i,\nu}(z_1, z_2)$

- Producer serving n has unit cost $C_{1n}(\omega) = \min_i\{C_{1ni}(\omega)\}$ but, under Bertrand competition, charges $C_{2n}(\omega)$.

- With CES utility,

$$P_n(\omega) = \min\{C_{2n}(\omega), \frac{\sigma}{\sigma - 1}C_{1n}(\omega)\}.$$

BEJK Results

- The probability that country i supplies a good in country n is $(\Phi_n \equiv \sum_{k=1}^{2} T_k(w_k\tau_{nk})^{-\theta})$:

$$\pi_{ni} = \frac{T_i(w_i\tau_{ni})^{-\theta}}{\Phi_n}.$$

- Denote X_{ni} as the total sales of goods from i to country n and X_n as the total sales:

$$X_{ni} = \pi_{ni} Y_n,$$

  where Y_n on the RHS rather than X_n (BEJK) due to royalty.

- Under $\theta + 1 > \sigma$, the price index is $P_n = \eta \Phi_n^{-\frac{1}{\theta}}$.

- A fraction $\frac{\theta}{1+\theta}$ of revenue goes to variable cost.

Innovating Firms

- The GPT winner's total profit is (zero marginal cost): $\Pi_{\nu}^{G} = \frac{\beta}{1+\theta}\left(X_{1\nu} + X_{2\nu}\right)$.
- GPT monopoly's value: $V_{\nu+1} = \frac{\Pi_{\nu+1}^{G}}{r+\lambda(R_{\nu+1})}$.
- R&D labor R_{ν} hired for innovating a new GPT is by

$$\max_{R_{\nu}} \lambda\left(R_{\nu}\right) \frac{V_{\nu+1}}{P_{1,\nu+1}} - \frac{w_{1,\nu}}{P_{1,\nu}} R_{\nu}.$$

- FOC of the innovating firms:

$$\frac{\beta\left(X_{1,\nu+1} + X_{2,\nu+1}\right)}{(1+\theta)P_{1,\nu+1}} \frac{\lambda'\left(R_{\nu}\right)}{r + \lambda\left(R_{\nu+1}\right)} = \frac{w_{1,\nu}}{P_{1,\nu}}. \tag{1}$$

Labor Markets

- Resource constrant:

$$R_1 + M_1 + L_1 = N_1, \qquad M_2 + L_2 = N_2.$$

- Expected payoff of entrepreneur equals wages.

$$\frac{1-\beta}{1+\theta}\frac{X_{i\nu}}{M_{i\nu}} = v_{i\nu} = w_{i\nu} = \frac{\theta}{1+\theta}\frac{X_{i\nu}}{L_{i\nu}}. \tag{2}$$

$\implies M_{iv} = \frac{1-\beta}{\theta} L_{iv}$, which implies that

$$L_{2\nu} = \frac{\theta}{1-\beta+\theta} N_2, \qquad M_{2\nu} = \frac{1-\beta}{1-\beta+\theta} N_2. \tag{3}$$

$$L_{1\nu} = \frac{\theta}{1-\beta+\theta}\left(N_1 - R_\nu\right), \qquad M_{1\nu} = \frac{1-\beta}{1-\beta+\theta}\left(N_1 - R_\nu\right) \tag{4}$$

Goods Markets

- Goods market clearing:

$$\begin{aligned} Y_{1\nu} &= X_{1\nu} + \frac{\beta}{1+\theta} X_{2\nu} = X_{11,\nu} + X_{12,\nu}, \\ Y_{2\nu} &= X_{2\nu} - \frac{\beta}{1+\theta} X_{2\nu} = X_{21,\nu} + X_{22,\nu}. \end{aligned}$$

- Trade imbalance:

$$\pi_{12} Y_1 = \pi_{21} Y_2 + \frac{\beta}{1+\theta} X_2,$$

and by defining $w = \frac{w_1}{w_2}$, $t_0 = \frac{t_{10}}{t_{20}}$, $m_\nu = \frac{M_{1\nu}}{M_{2\nu}}$, this becomes

$$w^{1+\theta} = \frac{m t_0 w^{-\theta} + \tau^{-\theta}}{m t_0 (w\tau)^{-\theta} + 1} \frac{1+\theta-\beta}{1+\theta} + \frac{\beta \tau^{\theta}}{1+\theta}. \tag{5}$$

BGP

- Balanced growth path (BGP) with constant $\lambda(R)$ and hence constant growth rates.

- For each generation ν, let $w_{1,\nu} = 1$ and $w_\nu = 1/w_{2,\nu}$ denote the wage ratio.
- 8 equilibrium conditions for the 8 endogenous variables $\{M_1, M_2, L_1, L_2, P_1, P_2, w, R\}$
  - labor market clearing with occupational choices (2 in North, 2 in South)
  - BEJK's price index
  - trade (im)balance
  - GPT innovator FOC

Trade and Sustained Growth

- On the BGP, the first-order condition on R can be written as

$$\frac{\beta\left(X_1+X_2\right)}{(1+\theta)w_1}\frac{P_{1,\nu}}{P_{1,\nu+1}}=\frac{r+\lambda\left(R\right)}{\lambda'\left(R\right)}, \tag{6}$$

of which the LHS is referred to as the **R&D multiplier**:

$$\frac{\beta}{1+\theta}\frac{X_1+X_2}{w_1}\times\gamma^{\frac{1}{\theta}}\quad\propto\quad\frac{\beta\gamma^{\frac{1}{\theta}}}{1-\beta+\theta}\left(N_1-R+\frac{N_2}{w(R)}\right)$$

- Because $t_0>1$, $w=w_1/w_2>1$, and a trade liberalization reduces $w\left(R\right)$ for given R, thereby increasing the R&D multiplier for given R.

- Trade liberalization (a $\tau\downarrow$) increases equilibrium R.

Trade and Sustained Growth

- The North-South structure is instrumental to the trade-growth link.
- After accounting for the decline of price indices due to technology advances, the general equilibrium object that affects GPT innovation is the global sales of differentiated products denominated in the North's wage, $(X_1 + X_2) / w_1$, which reflect the ratio of marginal benefit to marginal cost of GPT innovation.
- This ratio increases when $\tau \downarrow$
  - When the world is more integrated, the world taps into the South's resources more, resulting in factor-price equalization, which increases the global sales denominated in the North's wage.

Quantitative Model

- The model is extended to a multi-country framework with a North-South structure.
- Incorporates intermediate inputs by a roundabout production. Production function of a variety:

$$y_i(\omega) = Bz_i(\omega)[\ell_i(\omega)]^{\alpha}[b_i(\omega)]^{1-\alpha}.$$

- GPT innovators and the monopoly are MNCs that hire research workers from multiple North countries.

Quantitative Model

- The value of an innovation at time v:

$$V_{v+1} = \frac{\beta \sum_{i=1}^{I} X_{i,v+1}}{(1+\theta)[r + \lambda(R_{v+1}^{W})]}.$$

- Arrival rate function: $\lambda(R^W)$, where R^W is given by

$$R^W = \frac{\prod_{i=1}^{I} R_i^{\mu_i}}{\prod_{i=1}^{I} (\mu_i)^{\mu_i}}$$

such that $\sum_i \mu_i = 1$, and $\mu_i = 0$ if i is a South country.

Quantitative Model

- An GPT innovator's problem is

$$\max_{R_v^W} \frac{\lambda(R_v^W)V_{v+1}}{P_{v+1}} - \frac{w_v^R}{P_v} R_v,$$

where P_v and w_v^R are the Cobb-Douglas composite of price indices and wages, respectively.

- FOC gives the following equation to solve for optimal R^W

$$\frac{\beta}{1+\theta} \times \gamma^{\frac{1}{\theta\alpha}} \times \frac{\sum_i X_i}{w_v^R} = \frac{r+\lambda(R^W)}{\lambda'(R^W)}$$

Quantitative Model

- A fraction μ_i of royalty payment to the GPT firm is given to the branch at country i. So the national income is given by

$$Y_{i,\nu} = \frac{1-\beta}{1+\theta} X_{i,\nu} + w_{i,\nu} L_{i,\nu} + \frac{\beta \mu_i}{1+\theta} \sum_{n=1}^{I} X_{n,\nu}$$

- Labor markets in each North country i:

$$M_{i,\nu} = \frac{1-\beta}{1-\beta+\theta\alpha}(N_i - R_{i,\nu})$$

$$L_{i,\nu} = \frac{\theta\alpha}{1-\beta+\theta\alpha}(N_i - R_{i,\nu})$$

- The remainder is BEJK.

Welfare

- $x \equiv X_1 / X_2$, $w \equiv w_1 / w_2$.
- Under $\rho > g$, lifetime utility on the BGP is:

$$\begin{aligned} U_n &= \int_0^\infty \left[C_{n0} e^{gt} \right] e^{-\rho t} dt \\ &= \frac{1}{\rho - g} \frac{Y_{n0} / N_n}{P_{n0}}. \end{aligned}$$

Welfare

Examine welfare changes in relative terms:

$$\frac{U_i'}{U_i} = \frac{\rho - k_y}{\rho - k_y'} \times \frac{Y_{i,0}'}{Y_{i,0}} \times \frac{P_{i,0}}{P_{i,0}'} = \frac{\rho - k_y}{\rho - k_y'} \times \frac{Y_{i,0}'/w_{i,0}'}{Y_{i,0}/w_{i,0}} \times \frac{w_{i,0}'/P_{i,0}'}{w_{i,0}/P_{i,0}}$$

$$= \frac{\rho - k_y}{\rho - k_y'} \times \frac{Y_{i,0}'/w_{i,0}'}{Y_{i,0}/w_{i,0}} \times \left(\frac{\pi_{ii}'}{\pi_{ii}}\right)^{-\frac{1}{\theta\alpha}}$$

$$\equiv GR_i \times IG_i \times ACR_i.$$

GR: growth-rate effect
IG: income-gains effect – the effect of income-wage ratio

Welfare

- The above decomposition does not reveal the true dynamic gains from trade because of the general equilibrium effects.
- Comparison with a purely static version of the model: $\kappa = 0$ (no incentive to innovate, and $R = 0$ in equilibrium).
- **Proposition 1**: In the static model,
  1. The equilibrium growth rate is zero ($g = 0$) and thus GR$= 1$.
  2. The ratio of entrepreneurship activities between two countries $m = M_1 / M_2$ becomes a constant.
  3. If $\beta = 0$, then IG$= 1$ and $U_1' / U_1 =$ACR.

Quantification

- Preset parameters:
  - $r = 5\%, \rho = 3\%, \gamma = 1.1017$ (Aghion et al. 2019)
  - $\theta = 5.03$ (preferred value from Head and Mayer 2014)
- Labor share $\alpha = 0.56$ is calibrated by the value added as a fraction of gross output for the US in the WIOD data.
- From the World Development Indicators (WDI) and the Global Report of Global Entrepreneurship Monitor (GEM):
  - M_i: number of entrepreneurs
  - R_i: number of researchers
  - N_i: employment
  - L_i: Production workers, $L_i = N_i - R_i - M_i$.
- Sample of countries: 52.
- Use Penn World Tables (PWT) to select those with at least 67% of the US real GDP per worker as the North countries.

Quantification

- The R&D share μ_i for each North country i is calibrated via:

$$\mu_i = \frac{\frac{w_i R_i}{P_i}}{\sum_{i=1}^{I_N} \frac{w_i R_i}{P_i}},$$

where w_i / P_i is proxied by the real GDP per worker, and R_i is proxied by the number of researchers obtained from the WDI.

- β, directly affects the profit share of revenue of differentiated-product firms, as well as the royalty payments received by the GPT, which are the GPT's profit.

- β is chosen to match the profit rate of 0.154. We obtain $\beta = 0.074$.

Quantification

- Using trade flows data, bilateral trade costs τ_{ni}'s are estimated from the gravity equation following standard procedure.
- Following Fieler (2011) and Ravikumar et al. (2019), we back out $\{T_i\}$ by solving

$$
\begin{aligned}
T_i C_i^{-\theta} &= \exp(\hat{D}_i^{exp}) \\
C_i &= \left(w_i^{data}\right)^{\alpha} P_i^{1-\alpha} \\
P_i &= \left(\sum_{m=1}^{I} T_m [C_m \tau_{i,m}]^{-\theta}\right)^{-\frac{1}{\theta}}.
\end{aligned}
$$

- With data values of M_i from the GEM, we then compute $t_{i0} \propto T_i / M_i$.
- In sum, the relative technology stocks $\{t_{i0}\}$ are how the model rationalize the estimated exporter fixed effects, consistent with estimated trade costs and observed country-specific wages and adjusted for entrepreneurial activities.

Quantification

- The arrival rate as: $\lambda(R) = \kappa R^{\epsilon}$, with $\kappa > 0$, $\epsilon \in (0, 1)$.
- The two parameters κ and ϵ are solved simultaneously to match the following two targets.
  1. The annual real income growth rate during 1980–2014: 1.8977%. The model counterpart of the annual growth rate is given by $\gamma^{\frac{\lambda(R)}{\theta\alpha}} - 1$.
  2. The employment share of R&D researchers, $\sum_{i \in \text{North}} R_i^{\text{data}} / \sum_{i \in \text{North}} N_i^{\text{data}}$. Using the WDI data, the employment share of researchers is 0.58%.
- The resulting $(\kappa, \epsilon) = (2.04, 0.20)$.

Autarky to Benchmark

- Average of bilateral trade costs: 3.17
- g_y^{annual}: 1.538% to 1.898%

	Total Gains(%)	GR Gains(%)	IG Gains(%)	ACR Gains(%)
Avg (weighted)	30.62	27.4	0.14	3.07
North Avg (weighted)	32.07	27.4	0.67	3.99
South Avg (weighted)	30.23	27.4	0	2.82
		Share of GR Gains(%)	Share of IG Gains(%)	Share ACR Gains(%)
Avg (weighted)		89.51	0.46	10.03
North Avg (weighted)		85.45	2.1	12.45
South Avg (weighted)		90.66	0	9.34

Table: Simple Decomposition of Total Gains

Autarky to Benchmark

- The simple decomposition does not reveal the true dynamic gains because changes in R^W also affect general equilibrium objects Y_i, w_i, and P_i, which in turn affects the IG and ACR gains.
- To evaluate the true dynamic gains, we compute the static gains from trade obtained when $\kappa = 0$ (hence $R^W = 0$ in equilibrium).

	Total gains (%)	Static gains (%)	Dynamic gains (%)	Dynamic share (%)
Avg (weighted)	30.62	3.35	27.27	89.05
North Avg (weighted)	32.07	5.29	26.78	83.51
South Avg (weighted)	30.23	2.83	27.4	90.63

Table: Dynamic vs Static Gains (%)

Trade Liberalization

- 25% reduction of trade costs from observed trade costs, of which the average is 3.17.
- g_y^{annual}: 1.8977% to 1.8989%

	Total Gains(%)	GR Gains(%)	IG Gains(%)	ACR Gains(%)
Avg (weighted)	3.72	0.11	0.0	3.61
North Avg (weighted)	3.88	0.11	0.01	3.76
South Avg (weighted)	3.68	0.11	0	3.57
		Share of GR Gains(%)	Share of IG Gains(%)	Share ACR Gains(%)
Avg (weighted)		3.03	0.05	96.92
North Avg (weighted)		2.9	0.24	96.85
South Avg (weighted)		3.06	0	96.94

Table: Simple Decomposition of Total Gains

Trade Liberalization

Dynamic vs Static Gains (%)

	Total gains (%)	Static gains (%)	Dynamic gains (%)	Dynamic share (%)
Avg (weighted)	3.722	3.614	0.107	2.883
North Avg (weighted)	3.882	3.764	0.118	3.049
South Avg (weighted)	3.678	3.574	0.104	2.836

Table: 25% Reduction in Trade Costs from the Benchmark (%)

The Role of Intermediate Inputs

- Shut down intermediate inputs ($\alpha = 1$) and re-calibrate the model.
- Simple Decomposition of Total Gains from Autarky to Benchmark

	Total Gains(%)	GR Gains(%)	IG Gains(%)	ACR Gains(%)
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		Share of GR Gains(%)	Share of IG Gains(%)	Share ACR Gains(%)
Avg (weighted)		89.51	0.46	10.03
North Avg (weighted)		85.45	2.1	12.45
South Avg (weighted)		90.66	0	9.34

Table: With Intermediate Inputs

	Total Gains(%)	GR Gains(%)	IG Gains(%)	ACR Gains(%)
Avg (weighted)	39.9	38.12	0.07	1.71
North Avg (weighted)	40.68	38.12	0.32	2.24
South Avg (weighted)	39.69	38.12	0	1.57
		Share of GR Gains(%)	Share of IG Gains(%)	Share ACR Gains(%)
Avg (weighted)		95.55	0.17	4.29
North Avg (weighted)		93.71	0.78	5.51
South Avg (weighted)		96.05	0	3.95

Table: Without Intermediate Inputs ($\alpha = 1$)

Sensitivity Analysis

- The quantitative results are sensitive to the choice of θ, but not to the choice of γ.
- Recall $\gamma^{\frac{\lambda(R)}{\theta\alpha}} - 1 = 1.8977\%$. A smaller θ, say, 4, imply higher firm productivity and larger global market size and hence increases the growth rate.
- But to rationalize the same long run growth rate, innovation parameters must decrease. This results in smaller dynamic and total gains.
- The results are insensitive to γ because ...

Conclusion

- This paper develops a dynamic model of trade based on GPT advancement and evaluates dynamic gains from trade.
- North-South structure is crucial for entailing a positive link between trade and growth.
- The welfare formula can be decomposed into a growth-rate effect, an income-gains effect, and the ACR statistic.
- Large total gains from trade: the dynamic mechanism amplifies the total gains by about nine times larger.
- Dynamic gains from trade are larger when initial trade costs are higher.
- The world with intermediate goods features smaller dynamic gains and larger static gains.