Technology Adoption and the Latin American TFP Gap

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Motivation

- Large and persistent income gap between countries in Latin America and the Caribbean (LAC) and the United States (US).
- Total Factor Productivity (TFP) is among the leading factors of the observed income gap.
  - Caselli (2013), Cole et al (2005): TFP in LAC is about half of that of the US

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  - Caselli (2013), Cole et al (2005): TFP in LAC is about half of that of the US
- This paper: To what extent does *technological backwardness* due to **adoption lags** account for the difference in TFP between LAC and the US?

Related literature

- Identifying the technology component of TFP differences across countries is not trivial.
- Previous literature uses the prevalence of specific technologies (e.g. Comin and Hobijn, Comin and Mestieri)
- Relationship between the technologies and TFP is not clear
  - Assumes a mapping between the prevalence of specific technologies and aggregate productivity.
  - Which technologies are important for aggregate TFP?
- In this paper
  - Agnostic about which technologies are important.
  - Directly measure technological adoption through its effect on TFP.

Empirical Strategy

- Exploit lagged comovement to identify a technological component of productivity growth.
  - Identifying assumption: any shock to productivity growth in the frontier country (the US) that affects the adopting countries (LAC) with a lag is a technology shock.

Results

- Point estimate: bulk of technology adoption happens within 8-10 years.
- Upper bound of confidence interval:
  - technologies are fully adopted after 8-10 years
  - technology gap between LAC and the US is roughly constant over time.

Outline

- Conceptual Framework
- Time Series Analysis
- A Theory of Technology Adoption

Decomposing total factor productivity (TFP)

- $Y_{i,t} = A_{i,t}F(K_{i,t}, L_{i,t})$ where $A_{i,t}$ is TFP

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  - $X_{i,t}$ is technology
  - $Z_{i,t}$ is misallocation, competition, demand, unobserved capacity utilization, etc
- The growth rate of $A_{i,t}$ satisfies:

$$\Delta \ln(A_{i,t}) = \Delta \ln(X_{i,t}) + \Delta \ln(Z_{i,t})$$

Growth rates written in lower-case (e.g., $x_{i,t} = \Delta \ln(X_{i,t})$):

$$a_{i,t} = x_{i,t} + z_{i,t}$$

Technology adoption

- Frontier country (US); adopting country(ies) (LAC).
- Technology growth in the adopting country is a function of lagged growth levels of the frontier technology:

$$x_{lac,t} = \sum_{j=0}^{\infty} \lambda_j x_{us,t-j}$$

$$\bar{x}_{lac} = E\left(\sum_{j=0}^{\infty} \lambda_j x_{us,t-j}\right) = \bar{x} \sum_{j=0}^{\infty} \lambda_j$$

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- Long run effect of $x_{us,t}$ is $\sum_{j=0}^{\infty} \lambda_j$
- Technology growth rate differential

$$E\left(x_{us,t} - x_{lac,t}\right) = \bar{x}\left(1 - \sum_{j=0}^{\infty} \lambda_j\right)$$

The Model: State Space Representation

$$
\begin{aligned}
a_{us,t} - \bar{a}_{us} &= (z_{us,t} - \bar{z}_{us}) + (x_t - \bar{x}_t) && (1) \\
a_{lac,t} - \bar{a}_{lac} &= (z_{lac,t} - \bar{z}_{lac}) + \sum_{j=0}^{\infty} \lambda_j (x_{t-j} - \bar{x}) && (2) \\
z_{i,t} - \bar{z}_i &= \rho_i (z_{i,t-1} - \bar{z}_i) + \nu_{i,t} && (3) \\
x_t - \bar{x} &= \alpha (x_{t-1} - \bar{x}) + \epsilon_t && (4)
\end{aligned}
$$

$$
\begin{bmatrix} \nu_t^{us} \\ \nu_t^{lac} \\ \epsilon_t \end{bmatrix} \sim WN(0, \Omega) \qquad \Omega = \begin{bmatrix} \sigma^2_{us,us} & \sigma^2_{us,lac} & 0 \\ \sigma^2_{lac,us} & \sigma^2_{lac,lac} & 0 \\ 0 & 0 & \sigma^2_{x,x} \end{bmatrix}
$$

$$
\mid \alpha \mid, \mid \rho_{us} \mid, \mid \rho_{lac} \mid < 1
$$

$$
0 \leq \sum_{j=0}^{\infty} \lambda_j \leq 1
$$

How to estimate infinite number of λ_j

- We restrict λ_j to follow a "discrete normal" form

$$\lambda_j = p_1 \exp(-\frac{(j-p_2)^2}{p_3})$$

  - Similar to "Shrinkage estimators"
  - Yield curve estimation (Diebold et al., 2006)
  - Restricted distributed lag models:Koyck (1954),Solow (1960), Almon (1965), Chetty (1971), Heaton and Peng(2012)

The Model: State Space Representation

$$\begin{aligned} a_{us,t} - \bar{a}_{us} &= (z_{us,t} - \bar{z}_{us}) + (x_t - \bar{x}_t) && (5) \\ a_{lac,t} - \bar{a}_{lac} &= (z_{lac,t} - \bar{z}_{lac}) + \sum_{j=0}^{\infty} \lambda_j (x_{t-j} - \bar{x}) && (6) \\ z_{i,t} - \bar{z}_i &= \rho_i (z_{i,t-1} - \bar{z}_i) + \nu_{i,t} && (7) \\ x_t - \bar{x} &= \alpha (x_{t-1} - \bar{x}) + \epsilon_t && (8) \end{aligned}$$

$$\begin{bmatrix} \nu_t^{us} \\ \nu_t^{lac} \\ \epsilon_t \end{bmatrix} \sim WN(0, \Omega) \qquad \Omega = \begin{bmatrix} \sigma^2_{us,us} & \sigma^2_{us,lac} & 0 \\ \sigma^2_{lac,us} & \sigma^2_{lac,lac} & 0 \\ 0 & 0 & \sigma^2_{x,x} \end{bmatrix}$$

$$| \alpha |, | \rho_{us} |, | \rho_{lac} | < 1$$

$$\lambda_j = p_1 \exp(-\frac{(j - p_2)^2}{p_3}) \geq 0, \ \ j = 0, \ldots, \infty \qquad 0 \leq \sum_{j=0}^{\infty} \lambda_j \leq 1$$

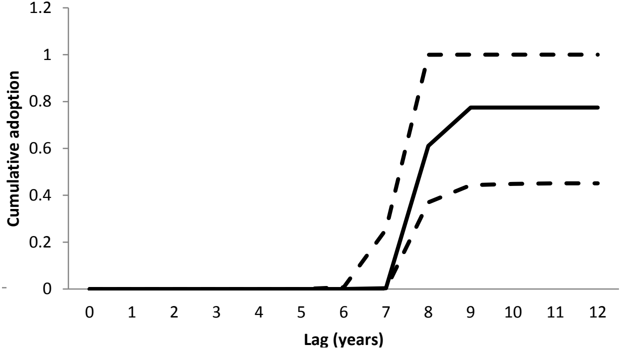
Estimation

- (Quasi) Maximum likelihood estimation
- A unified state-space modeling approach that let simultaneously estimate the model and extract the technology part of TFP growth.
  - Kalman filter delivers optimal filtered and smoothed estimates of the unobserved components of the model.
- We report 90% confidence intervals constructed with a bootstrap methodology
  - Small sample, bounded parameter space
  - Parameters of interest (λ_j) are non-linear transformations of estimated parameters p_1, p_2, p_3

Data

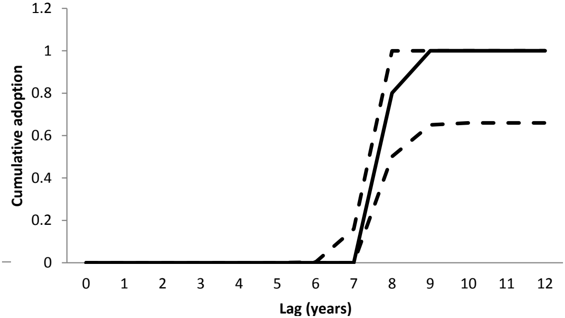
- Solow residual constructed from the Penn World Tables (1960-2009) following Caselli (2005)
  - With and without human capital from Barro and Lee (2001)
- GDP per capita.
- Begin with LAC weighted average

Baseline Results: Aggregate cumulative adoption ($\sum_{j=0}^{T} \lambda_j$)



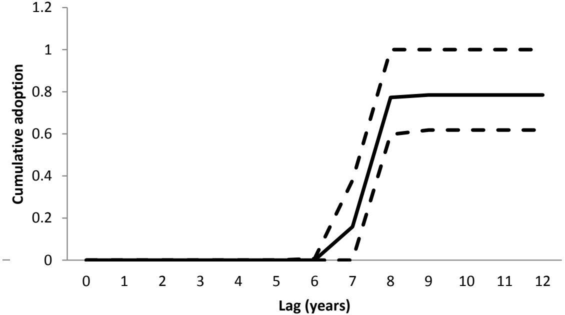
Note: dotted lines represent 90% confidence intervals.

Baseline Results: Aggregate cumulative adoption (TFP without human capital)



Note: dotted lines represent 90% confidence intervals.

Baseline Results: Aggregate cumulative adoption (GDP)

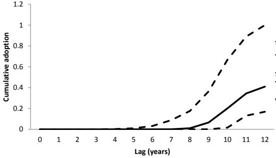


Note: dotted lines represent 90% confidence intervals.

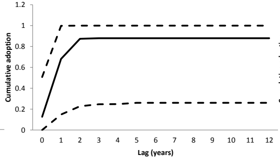
Industry level: data

- Groningen 10 sector database (9 sectors for LAC; government services and community, social and personal services are combined), 1950-2005
- Real value-added per worker
- Weighted average for LAC (weighted by total real value added in the sector)

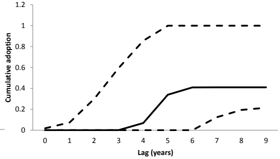
Industry level adoption rates (annual growth)



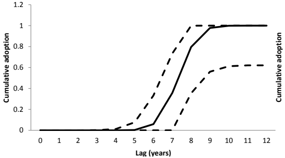
(a) Agriculture



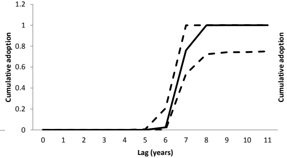
(b) Mining



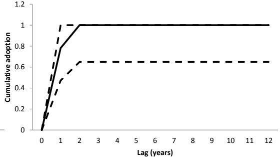
(c) Construction



(d) Manufacturing



(e) Wholesale and retail, hotels and restaurants

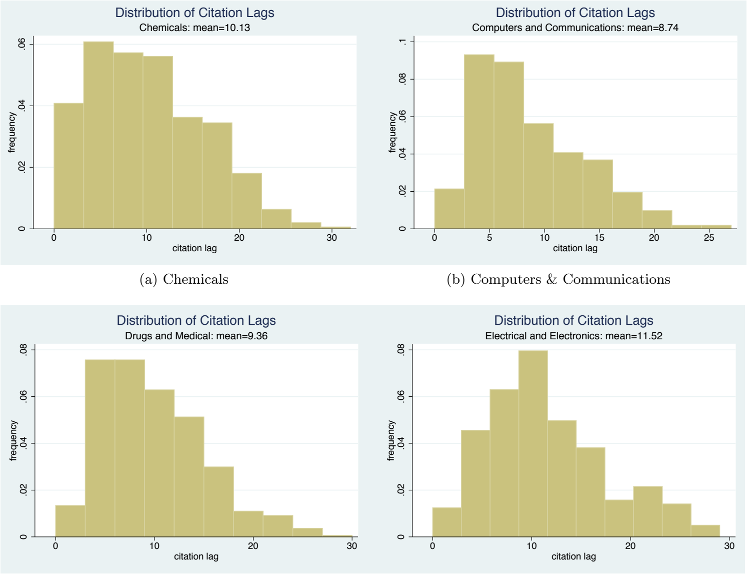


(f) Transport, storage, and communication

Comparing results with the previous literature

- Compared to the existing estimates in the literature, our findings suggest a relatively modest adoption lags.
- For instance, Comin, Hobijn, and Rovito [2006] and Comin and Hobijn [2010] estimate an average technology adoption lag of 45 years (averaged across many different countries and technologies).
  - One way to reconcile the findings is to note that these papers look at a simple average of technologies, while our analysis aims to "weigh" technologies by their contribution to aggregate TFP.
- Consistent with our results, they find shorter adoption lags for the technologies that we believe are more essential for the aggregate TFP
  - 14 years adoption lags for PCs and 15 years for cell phones.

Age of a US patent when cited by a LAC patent



(a) Chemicals

(b) Computers & Communications

(c) Drugs and Medical

(d) Electrical and Electronics

A Theory of Technology Adoption

- A simple theory regarding the potential determinants of adoption lags and its implication on income gap between the US and Latin America over the 20th century.
- Focus on the impact of static wedges (Z_t) on optimal technology adoption decision.
- Based on Aghion and Howitt (2009) and Acemoglu, Aghion and Zilibotti (2006)
- One potential interpretation of these wedges is the misallocation of production factors in the economy.
  - Hsieh and Klenow (2009, 2014), Restuccia and Rogerson (2008).
- Relates distance to frontier literature to misallocation literature.

Model

- In each country, a unique final good, is produced competitively using a continuum of intermediate inputs according to

$$Y_{it} = L^{\alpha} \int X_{ijt}^{\alpha} y_{ijt}^{1-\alpha} dj$$

- X_{ijt} is the productivity in country i, sector j at time t.
- y_{ijt} is the intermediate good produced by monopolist.
- The marginal cost of producing each variety is $\tau_p \eta_i$ in terms of the final good, $\eta_i > 0$ and $\tau_p \geq 1$ is the static wedge in the economy.

Static Problem

- Demand for each variety

$$(1-\alpha)L^{\alpha}X_j^{\alpha}y_j^{-\alpha} = p_j$$

- Monopolist's problem

$$\pi_j = \max(p_j - \tau_p \eta)y_j$$

subject to demand.

- Profits

$$\pi_j = \Pi X_j Z$$

$\Pi = (1-\alpha)\alpha L, \quad Z \equiv \tau_p^{\frac{\alpha-1}{\alpha}}$

- Aggregate output

$$Y = XZL$$

$X \equiv \int X_j dj$

Technology Vintages and the World Knowledge Frontier

- Denote the world technology frontier by $\bar{X}\left(\bar{N}\right)$
  - $\bar{X}$ is the knowledge stock at the frontier after having adopted the $\bar{N}^{th}$ vintage technology.
- Every period, the frontier receives a new generation technology such that

$$\bar{N}_{t+1} = \bar{N}_t + 1$$

- The $\bar{N}^{th}$generation technology produces a growth rate of $\lambda_{\bar{N}}$ at the frontier

$$\frac{\bar{X}_{t+1}}{\bar{X}_t} = 1 + \lambda_{\bar{N}}$$

Technology Adoption

- The follower country (the LAC region) adopts technologies from the frontier.
- There is a mass of entrepreneurs that live for one period.
- In each period, a randomly selected entrepreneur is assigned to product line j.
- The entrepreneur has the option of adopting the knowledge stock from the frontier, in which case the productivity in j can increase from $X_j(N)$ to

$$\hat{X}_j(\bar{N}, N) = X_j(N) \prod_{k=N}^{\bar{N}} (1 + \lambda_k)$$

- Knowledge stock in j will improve from current vintage N to frontier vintage $\bar{N}$.

Technology Adoption

- μ_j is the probability of technology adoption in sector j chosen by the entrepreneur with a cost

$$\gamma \frac{\mu_j^2}{2} \hat{X}(\bar{N}, N)$$

- If the technology to be adopted is more advanced, the cost of adopting it is also higher.
- Adoption problem

$$\max_{\mu_j} \left\{ \mu_j \Pi Z \hat{X}(\bar{N}, N) - \gamma \frac{\mu_j^2}{2} \hat{X}(\bar{N}, N) \right\}$$

Optimal decision

$$\mu_j = \mu = \frac{\Pi Z}{\gamma}$$

Law of motion of the vintages in LAC

$$N_{t+1} = \mu \bar{N}_t + (1-\mu) N_t$$

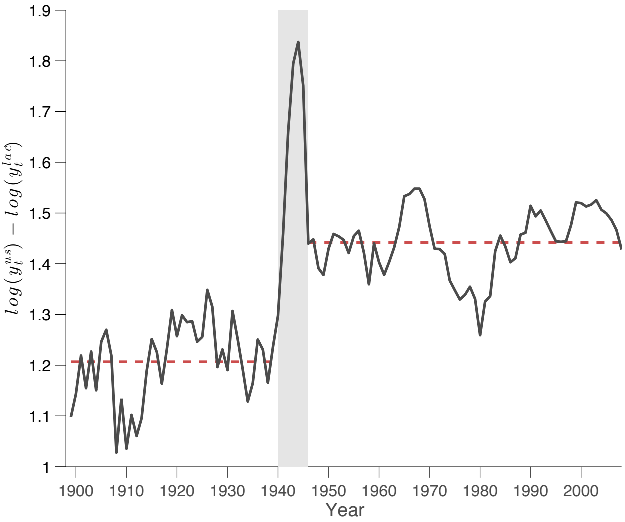
- Define the distance to the world vintage frontier as $n_t \equiv \bar{N}_t - N_t$

$$n_{t+1} = 1 + (1-\mu) n_t$$

- n_t converges in the long run

$$\lim_{t \to \infty} n_t = n^* = \frac{1}{\mu} = \frac{\gamma}{\Pi Z}$$

US vs LAC: Income Differences over Time



Can we explain the structural break with this model?

$$Y_{i,t} = A_{i,t} L_{i,t}$$
$$A_{i,t} = X_{i,t} Z_{i,t}$$
$$y_{i,t} = X_{i,t} Z_{i,t}$$

$$\ln\left(\frac{y_{us,t}}{y_{lac,t}}\right) = \ln\left(\frac{X_{us,t}}{X_{lac,t}}\right) + \ln\left(\frac{Z_{us,t}}{Z_{lac,t}}\right)$$

Can we explain the structural break with this model?

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$$\ln\left(\frac{y_{us,t}}{y_{lac,t}}\right) = \ln\left(\frac{X_{us,t}}{X_{lac,t}}\right) + \ln\left(\frac{Z_{us,t}}{Z_{lac,t}}\right)$$

- Assumption: $Z_{us,t} = 1$.

$$\ln\left(\frac{y_{us,t}}{y_{lac,t}}\right) = \ln\left(\frac{X_{us,t}}{X_{lac,t}}\right) - \ln\left(Z_{lac,t}\right)$$

Long run decomposition based on theory

$$\ln\left(\frac{Y_{us,t}}{Y_{lac,t}}\right) = \ln\left(\frac{(1+\lambda)^{n^*}X_{lac}}{X_{lac}}\right) - \ln Z_{lac}$$
$$= n^* \ln(1+\lambda) - \ln Z_{lac}$$
$$\ln\left(\frac{Y_{us,t}}{Y_{lac,t}}\right) = \frac{\gamma \ln(1+\lambda)}{Z_{lac}\Pi} - \ln Z_{lac}$$

- Static wedge not only has direct effect on the income difference, but also a indirect effect through its impact on technology adoption lags.
  - Higher static wedge lowers the return to technology adoption which, in turn, increases the equilibrium adoption lags.

Static wedges and income gap

	$\ln(Y_{us}/Y_{lac})$
Pre-war (1900-1940)	1.21
Post-war (1948-2006)	1.44
Implied $Z_{lac}^{pre}/Z_{lac}^{post}$	1.23

- Within each period, 10% of the observed income gap is attributed to the indirect effect of the static wedges on technology adoption and the rest coming from its direct effect.

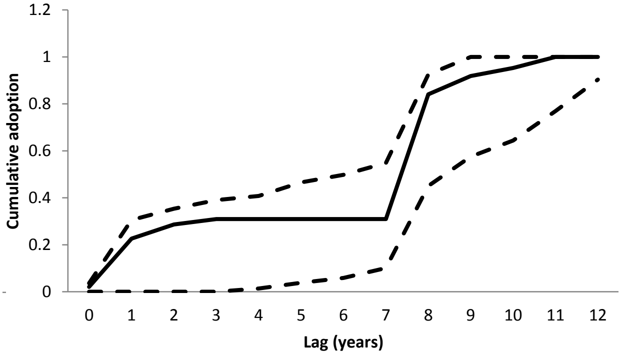
Testing the mechanism

- Testable implication of the model
  - If the static wedge is a major source of increased income difference, then the technology adoption lags should have increased between two periods.
- To test this empirical conjecture, we reestimate our econometric model with pre-war data.
  - Adoption lags between 1900-1940 was **4-5** years, which is almost half of our post-war estimates of **8-10** years.

Conclusion

- We introduced a new methodology for estimating the contribution of technology to aggregate TFP gaps using time series methods
- 8-10 year lag in technology adoption
  - Aggregate; country level; industry level
  - Consistent with micro evidence
- We introduce a simple theory of technology adoption that explores the idea that static distortions may reduce the incentives for technology adoption.
- Our theory seems consistent with the empirical estimates of adoption lag.
- Next:
  - Estimation for rest of the world
  - Correlate adoption lags with country specific characteristics

Relaxing Discrete Normal Assumption (TFP with human capital)



Note: dotted lines represent 90% confidence intervals.

A Model with Two Factors

Consider the the following model:

$$a_{i,t} = \sum_{\tau=0}^{s} \Lambda_{i,\tau} f_{t-\tau} + e_{i,t} \tag{1}$$

where the 2×1 vector $f_t = [f_{1,t}, f_{2,t}]'$ is the latent dynamic factor which includes 2 factors, the 1×2 vector $\Lambda_{i,\tau}$ is the dynamic factor loading for $f_{t-\tau}$, for countries $i = 1, 2, 3, ..., N$. The dynamic factor follows a $VAR(h)$ process;

$$f_t = \sum_{\tau=0}^{s} \Phi_{\tau} f_{t-\tau} + \varepsilon_t \tag{2}$$

Identification

- First define

$$\bar{\Lambda} = \begin{bmatrix} \Lambda_{10} \\ \Lambda_{20} \end{bmatrix}$$

which is a 2×2 matrix.

- **Identification I**: (i) $var(\varepsilon_t) \equiv Q = I_2$, (ii) $\bar{\Lambda}$ is a lower-triangular matrix with strictly positive diagonal elements
- The latter restriction says that TFP growth for the **first** country, $a_{1,t}$, is affected contemporaneously **only** by the **first** dynamic factor, and the second country, $a_{2,t}$, is affected contemporaneously by **both** dynamic factors, and *no restriction* for other countries.

Alternative Models

- Allowing for $x_{i,t}$ affecting $z_{i,t}$
  - Identification: α should be same across countries.

$$z_{i,t} = \rho_i z_{i,t-1} + \alpha x_{i,t} + \epsilon_{i,t}$$

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- A more general model with two common, correlated factors: (i) z_t^{global} and (ii) x_t
  - Identification: TFP growth for the first country, $a_{1,t}$, is affected contemporaneously **only** by the **first factor**, and the second country, $a_{2,t}$, is affected contemporaneously by **both factors**, and no restriction for other countries.

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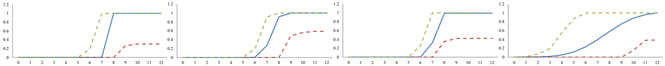
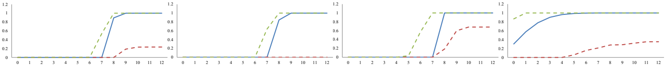
  - Identification: TFP growth for the first country, $a_{1,t}$, is affected contemporaneously **only** by the **first factor**, and the second country, $a_{2,t}$, is affected contemporaneously by **both factors**, and no restriction for other countries.
- Results are similar across different specifications.

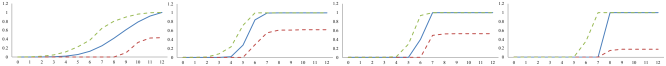
Country level adoption rates



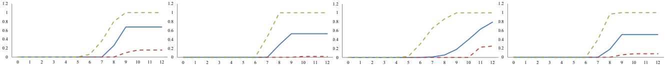
(a) Uruguay (b) Brazil (c) Argentina (d) Bolivia



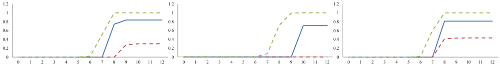
(e) Peru (f) Trinidad (g) Venezuela (h) Jamaica



(i) Guatemala (j) El-Salvador (k) Costa Rica (l) Chile



(m) Paraguay (n) Panama (o) Mexico (p) Honduras



(q) Ecuador (r) Dominican Repub- (s) Colombia

12 out of 19 countries: full adoption in $\leq$ 12 years (point estimates)