The Economic Geography of Innovation

Peter H. Egger\textsuperscript{1,2} \quad Nicole Püschel \textsuperscript{1}

\textsuperscript{1} ETH Zurich
\textsuperscript{2} CEPR, CESifo, WIFO

December 4, 2017
Technology and productivity are key drivers of production potential, attractiveness for mobile factors to locate, and for well-being.

Technological capabilities influenced by local innovations and innovations generated elsewhere (spillovers).

Many countries have introduced R&D investment incentive policies.

What is the economic value and the spatial impact of innovations in general and of such incentive schemes?
This Paper

In a first step
- Formulate and calibrate a multi-region general equilibrium model of international trade.
- The model builds on Allen and Arkolakis ’14 and Desmet et al. ’17\(^1\) and considers – beyond usual productivity shifters for the production of output – a productivity shifter for workers employed in innovation.

In a second step
- Structurally estimate this productivity shifter (and other model parameters) using region-specific patent registrations and country-specific R&D- investment incentives.

In a third step
- Conduct counterfactual experiments in order to quantify the steady-state effects of innovation and specific innovation incentives for the spatial distribution of economic activity and well-being.

\(^1\)Henceforth: AA ’14 and DNRH ’17
The Model
Consider a world of $S$ regions $r$ on a two-dimensional surface, so $r = 1, \ldots, S$.

Region $r$ has land density $G_r > 0$, and $G_r$ is normalized by $\frac{1}{S} \sum_{r=1}^{S} G_r$.

Each region $r$ is unique in terms of: amenities, productivity, and geography.

In each location, firms produce product varieties $\omega$, innovate, and trade subject to iceberg transport costs.

Firms have an incentive to innovate as it improves their productivity and allows them to post a higher bid for land (land competition).

Innovation is less costly in locations with innovation incentive schemes.

Benefits from innovation last only for one period, then technology diffuses completely.

The world economy is populated by $\bar{L}$ agents, who are endowed with one unit of labor each and are fully mobile across regions.

- **Static part** of the model follows AA ’14 and Eaton and Kortum ’02 (EK ’02).
- **Dynamic part** of the model follows Desmet and Rossi-Hansberg ’14.
The Role of Innovation for Production (1)

- A firm’s production of variety $\omega$ per unit of land in intensive form is defined as
  \[ q_{rt}(\omega) = \varphi_{rt}(\omega)^{\gamma_1} z_{rt}(\omega) L_{rt}(\omega)^{\mu} \quad \gamma_1, \mu \in (0, 1]. \quad (1) \]

- A firm’s productivity is determined by its decision to innovate, $\varphi_{rt}(\omega)$, and an exogenous, good-specific productivity shifter, $z_{rt}(\omega)$.

- For each variety $\omega$, $z_{rt}$ is the realization of a random variable $Z_{rt}$ that is drawn form a Fréchet distribution.

\[ F(z, r) = e^{-T_{rt}z^{-\theta}} \]

- $T_{rt} = \tau_{rt}L_{rt}^\alpha$, $\alpha \geq 0$ and $\theta > 0$

- $\tau_{it}$ is evolving according to
  \[ \tau_{rt} = \varphi_{rt-1}^{\gamma_1\theta} \frac{1}{S} \left[ \int_S \tau_{st-1} ds \right]^{1-\gamma_2} \tau_{rt-1}. \quad \text{(2)} \]

  - Note: If $\gamma_2 < 1$ then the model implies global diffusion of technology.

- Productivity draws are i.i.d across time and goods, but correlated across regions.
All products are produced under perfect local competition.

Competition for land implies that firms bid until they break even.

Firms have an incentive to invest in innovation as it increases their productivity in (1) and eventually increases their bid for land.

Innovation is produced under Cobb-Douglas technology and constant returns to scale: 

$$\phi_{rt}(\omega) = \left( \frac{1}{\nu} L_{rt}^{\text{inno}}(\omega) h_{rt} \right)^{1/\xi}, \text{ with } h_{rt} \geq 1.$$  

Hence, to innovate, a firm has to employ additional units of labor

$$L_{rt}^{\text{inno}}(\omega) = \nu \phi_{rt}(\omega)^{\xi} h_{rt}^{-1}. \quad (3)$$

where $h_{rt}$ is an innovation-worker-specific productivity shifter.
The Model

The Role of Innovation for Production (3)

- Firms enjoy the benefit of their innovation for only one period, in the next period all entrants to the market have the same access to technology.
- This simplifies the dynamic profit maximization to a sequence of static problems:

\[
\max_{L_r(\omega), \phi_r(\omega)} \quad p_r(\omega) \phi_r(\omega)^{\gamma_1} z_r(\omega) L_r(\omega)^\mu - w_r[L_r(\omega) + \phi_r(\omega)^\xi h_r^{-1}] - b_r
\]

- Prices of a good produced in \( r \) and sold in \( r \) are: \( p_r(\omega) = o_r / z_r(\omega) \).
  - An individual firm takes the input costs (\( o_r \)) as given.
  - Productivity draws affect prices without changing input costs.
- Unit costs \( o_r \) are defined as follows

\[
o_r \propto b_r^{(1-\mu) - \frac{\gamma_1}{\xi}} h_r^{-\frac{\gamma_1}{\xi}} w_r^{(\mu + \frac{\gamma_1}{\xi})}.
\]  

(4)

- \( b_r \) is the firm’s bid rent for land, which increases with the level of innovation

\[
b_r = \left[ \frac{\xi(1-\mu)}{\gamma_1} - 1 \right] w_r \phi_r(\omega)^\xi h_r^{-1}.
\]  

(5)
The Role of Innovation for Total Employment

- Total employment in region $r$ at period $t$ is the sum of production workers, $L_{rt}(\omega)$, and innovation workers, $\nu \phi_{rt}(\omega) h_{rt}^{-1}$, so

$$\bar{L}_{rt}(\omega) = L_{rt}(\omega) + \nu \phi_{rt}(\omega) h_{rt}^{-1} = L_{rt}(\omega) \left[ 1 + \frac{\gamma_1}{\mu \xi} \right]. \quad (6)$$

- The last equality follows from the first-order-condition ratio between production labor and innovation labor

$$\nu \phi_{rt}(\omega) h_{rt}^{-1} = \frac{\gamma_1}{\xi \mu} L_{rt}(\omega) = \frac{\gamma_1}{\mu \xi + \gamma_1} \bar{L}_{rt}(\omega). \quad (7)$$

- Production labor is proportional to total employment in all regions $r$. 
When choosing residence in region $r$, a representative worker in period $t$ derives utility from local amenities, $a_{rt}$, and from consuming a set of differentiated product varieties $\omega$ with CES preferences according to

$$u_{rt} = a_{rt} C_{rt} = a_{rt} \left[ \int_0^1 c_{rt}(\omega) \frac{\sigma-1}{\sigma} d\omega \right]^{\frac{\sigma}{\sigma-1}} \quad \text{with} \quad a_{rt} = \bar{a}_r \bar{L}_{rt}^{-\lambda} \quad (8)$$

- $\bar{a}_r$: time-invariant amenity attribute.
- $\lambda \geq 0$: congestion externalities parameter.
- $C_{rt}$: real consumption bundle.
- $\sigma \in (1, \infty)$: elasticity of substitution between varieties $\omega$. 

Egger and Püschel (ETH Zurich)
The Economic Geography of Innovation
December 4, 2017 10 / 52
Utility and Consumption (2)

- Agents earn income from work and from local ownership of land.
- Rents are assumed to be uniformly distributed across agents.
- Workers cannot write debt contracts with each other.
- Perfect local competition implies that each worker consumes all her income.
- Indirect utility:
  \[ u_{rt} = a_{rt}y_{rt} = a_{rt}\frac{w_{rt} + b_{rt}/\bar{L}_{rt}}{P_{rt}} \]  
  \[ u_{rt} = a_{rt}y_{rt} = a_{rt}\frac{w_{rt} + b_{rt}/\bar{L}_{rt}}{P_{rt}} \]  
  (9)

- Price index, \( P_{rt} \), is defined as
  \[ P_{rt} = \Gamma \left( \frac{1-\sigma}{\theta} + 1 \right)^{\frac{1}{1-\sigma}} \int_{S} T_{kt} [o_{kt}^r]^{1-\theta} dk \]  
  (10)

- As in EK '02 the share of consumption in region \( r \) of varieties produced in region \( s \) is determined by
  \[ \pi_{rst} = \frac{T_{rt} [o_{rt}^s]^{-\theta}}{\int_{S} T_{kt} [o_{kt}^s]^{-\theta} dk}, \forall r, s \in S. \]  
  (10)

- \( \zeta_{rs} > 1 \): iceberg costs of transporting a product from \( r \) to \( s \).
Equilibrium
Equilibrium in Each Period

Equilibrium in each period only depends on current profits, as each period is self-contained and firms are not forward-looking.

1. **Population density** is determined by the location-specific utility derived

   \[ \frac{G_r \bar{L}_{rt}}{\bar{L}} = \frac{u_{rt}^{1/\Omega}}{\int_S u_k^{1/\Omega} dk}, \quad \text{with} \quad \int_S G_r L_{rt} dr = \bar{L} \quad (11) \]

   - \( \Omega \): Fréchet parameter of a location-specific preference shock.
   - No other migration costs than ones captured by \( \bar{a}_r \).

2. **Wages** through product-market clearing that requires total revenues in region \( r \) to be equal to total expenditures on products of its customers:

   \[ w_{rt} G_r \bar{L}_{rt} = \int_S \pi_{rst} w_{st} G_s \bar{L}_{st} \, ds \quad \forall \, r, s \in S \quad (12) \]

Existence and Uniqueness

- An equilibrium exists and is unique if congestion forces are not smaller than agglomeration forces:

  \[ \frac{\alpha}{\theta} + \frac{\gamma_1}{\xi} \leq \lambda + 1 - \mu + \Omega. \]
Balanced Growth Path (BGP)

- If a BGP exists then all locations grow at the same rate and the spatial distribution of employment is constant.
- The investment decision will be constant but different across locations.
- There exists a unique growth path if

\[
\frac{\alpha}{\theta} + \frac{\gamma_1}{\xi} + \frac{\gamma_1}{[1 - \gamma_2]\xi} \leq \lambda + 1 - \mu + \Omega
\]

Dynamic agglomeration effect

- In a BGP aggregate welfare and real consumption depend on population size, the productivity shifter $h_{rt}$ and their distribution in space

\[
\frac{u_{rt+1}}{u_{rt}} = \frac{C_{rt+1}}{C_{rt}} \propto \left( \int_S (\bar{L}_s h_s)^{\frac{\theta \gamma_1}{[1 - \gamma_2] \xi}} ds \right)^{\frac{1 - \gamma_2}{\theta}}
\]
Calibration of the Model
Calibration: Overview

1. Preferences
\( \sigma = 4 \) Elasticity of substitution.
\( \lambda = 0.65 \) Relation between amenities and population.
\( \Omega = 0.5 \) Elasticity of migration flows w.r.t. income.

2. Technology
\( \alpha = 0.06 \) Elasticity of productivity w.r.t. population density.
\( \theta = 6.5 \) Trade elasticity.
\( \mu = 0.8 \) Labor share in production (non-land share).
\( \gamma_1 = 0.1130 \) Elasticity of tomorrow’s productivity w.r.t. today’s innovation.

3. Evolution of productivity
\( \gamma_2 = 0.9898 \) Elasticity of tomorrow’s productivity w.r.t. today’s productivity.
\( \xi = 125 \) Elasticity of innovation costs w.r.t. innovation.
\( \nu = 0.15 \) Intercept parameter in innovation cost function.

4. Transport Costs
Based on AA ’14 and Fast Marching Algorithm.

4. Other Trade Costs
\( \theta = 6.5 \) Elasticity of trade w.r.t. tariffs (tariffs from WDI).
\( \kappa = 0.078 \) Elasticity of trade w.r.t linguistic proximity (Melitz and Toubal, 2014).
Estimation
Amenity Parameter

- Amenities are defined as: \( a_{rt} = \bar{a}_r \bar{L}_{rt}^{-\lambda} \)
- We estimate the region-specific amenity shock \( \bar{a}_r \) and the amenity parameter \( \lambda \) for the baseline year 2005 as follows

\[
\log(a_r) = E(\log(\bar{a}_r)) - \lambda \log \bar{L}_r + \varepsilon_r^a 
\]  

\( a_r \): Amenity distribution (2005) is derived through an iterative process using the structure of the model.

\( \bar{L}_r \): Gridded population data (2005) from SEDAC.

\( \bar{L}_r \) is instrumented with a region-specific remoteness index, \( R_r = \text{weight}_{area} \left( \frac{1}{S} \sum_s \zeta_{rs} \right) \)

<table>
<thead>
<tr>
<th>First Stage</th>
<th>Dep. Var. log(( \bar{L}_r ))</th>
<th>Second Stage</th>
<th>Dep. Var. log(( a_r ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \log(R_r) )</td>
<td>-0.581*** (0.014)</td>
<td>( \log(\bar{L}_r) )</td>
<td>-0.650*** (0.034)</td>
</tr>
<tr>
<td>cons</td>
<td>16.113*** (0.060)</td>
<td>cons</td>
<td>9.604*** (0.473)</td>
</tr>
<tr>
<td>#obs</td>
<td>5633</td>
<td>#obs</td>
<td>5633</td>
</tr>
</tbody>
</table>

\( \bar{a}_r \equiv \exp(E(\log(\bar{a}_r)) + \varepsilon_r^a) \)
Technology Parameters

- The BGP implies (13). Taking logs and discretizing (13) gives
  \[
  \log(u_{rt+1}) - \log(u_{rt}) = \log(y_{rt+1}) - \log(y_{rt}) = (1 - \gamma_2) \frac{\theta}{\log(\eta)} + \frac{\gamma_1}{\xi} \log(\Psi) + \frac{\gamma_1}{\xi} \log(SL_n) + \frac{1 - \gamma_2}{\theta} \log(\sum_r \bar{L}_n^*)
  \]  

- \(\Psi = \frac{\gamma_1}{\gamma_1 + \mu \xi}, \quad L_n = 1000, \quad \bar{L}_n = \left[ \frac{L_{rt}}{L_n} \right]^\frac{\gamma_1}{(1 - \gamma_2) \xi}.

- \(y_{rt}, \bar{L}_n\): Gridded GDP p/c and population data from G-Econ Project.
- \(t\): 1990(5)2005

- We do a grid search for the minimum sum of squared residuals.
- We use the corresponding \(h_r\) for each value of \(\gamma_1\) as the estimation of \(h_r\) itself depends on \(\gamma_1\).
- Optimal parameter values: \(\gamma_1 = 0.1130, \gamma_2 = 0.9898\) (DNRH: \(\gamma_1 = 0.319, \gamma_2 = 0.99246\))
Estimation of $h_r$

- We estimate $h_{rt}$ using (7) and assume

$$\phi^{\xi}_{rt} = \text{Patents}^{\xi}_{rt} = \frac{\gamma_1}{\xi \nu [\mu + \gamma_1 / \xi]} \bar{L}_{rt} h_{rt}$$

(16)

- $\text{Patents}_{rt}$: registered patents per unit of land in region $r$ at year $t$ (PATSTAT).
- $\bar{L}_{rt}$: population density in region $r$ at year $t$ (SEDAC).

- We parametrize $h_{rt}$ by country-specific binary tax instruments (Boesenberg and Egger, 2016), such that:

$$h_{rt} = \exp(D_{ct}\beta + |\text{lat}_{rt}| D_{ct}\gamma)$$

(17)

- $D_{ct}$ includes binary variables on R&D policy instruments: $D_{\text{patentbox}_{ct}}, D_{\text{grants}_{ct}}, D_{\text{taxcredit}_{ct}}, D_{\text{taxholiday}_{ct}}, D_{\text{superd}_{ct}}, D_{\text{deduc}_{ct}}, D_{\text{eatrrd}_{ct}}$.

- We estimate (16) as a cross section by negative binomial regression (year=2005)

$$\text{Patents}_r = \exp(\beta_0 + \frac{1}{\tilde{\nu}} \log \tilde{L}_r + \frac{1}{\xi} \log h_r + \varepsilon_r)$$

(18)

where $\tilde{L}_r = \xi \nu [\mu + \gamma_1 / \xi] \bar{L}_r$ and $\varepsilon_r$ is the error term.
Countries with a few patents do not have a regional classification.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std.Dev.</th>
<th>Min.</th>
<th>Max.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patents per norm. unit of land (avg. 2000-2010)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1,201</td>
<td>8,058</td>
<td>0</td>
<td>375,281</td>
<td>5,470</td>
</tr>
<tr>
<td>One-region countries</td>
<td>988</td>
<td>9,044</td>
<td>0</td>
<td>113,542</td>
<td>163</td>
</tr>
<tr>
<td>One-region countries islands</td>
<td>4,233</td>
<td>18,549</td>
<td>0</td>
<td>113,542</td>
<td>38</td>
</tr>
<tr>
<td>One-region countries non-islands</td>
<td>1.511</td>
<td>3.475</td>
<td>0</td>
<td>18.025</td>
<td>125</td>
</tr>
<tr>
<td><strong>Patents per km² (avg. 2000-2010)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.026</td>
<td>0.172</td>
<td>0</td>
<td>8.012</td>
<td>5,470</td>
</tr>
<tr>
<td>One-region countries</td>
<td>0.021</td>
<td>0.193</td>
<td>0</td>
<td>2.424</td>
<td>163</td>
</tr>
<tr>
<td>One-region countries islands</td>
<td>0.09</td>
<td>0.396</td>
<td>0</td>
<td>2.424</td>
<td>38</td>
</tr>
<tr>
<td>One-region countries non-islands</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>125</td>
</tr>
</tbody>
</table>
### Summary Statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patents per norm. unit of land</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>patents&lt;sub&gt;r&lt;/sub&gt; (inv) avg 2000-2010</td>
<td>1,195</td>
<td>8,087</td>
<td>0</td>
<td>375,281</td>
</tr>
<tr>
<td>patents&lt;sub&gt;r&lt;/sub&gt; (inv) 2005</td>
<td>1,218</td>
<td>8,337</td>
<td>0</td>
<td>392,807</td>
</tr>
<tr>
<td>patents&lt;sub&gt;r&lt;/sub&gt; (app) avg 2000-2010</td>
<td>1,795</td>
<td>24,303</td>
<td>0</td>
<td>1,165,570</td>
</tr>
<tr>
<td>patents&lt;sub&gt;r&lt;/sub&gt; (app) 2005</td>
<td>1,814</td>
<td>24,282</td>
<td>0</td>
<td>1,178,841</td>
</tr>
<tr>
<td>log((\tilde{L}_r))</td>
<td>8.955</td>
<td>2.172</td>
<td>-1.585</td>
<td>15.811</td>
</tr>
<tr>
<td>Dtaxcredit&lt;sub&gt;c&lt;/sub&gt;</td>
<td>0.715</td>
<td>0.452</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Dsuperd&lt;sub&gt;c&lt;/sub&gt;</td>
<td>0.053</td>
<td>0.224</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Dtaxholiday&lt;sub&gt;c&lt;/sub&gt;</td>
<td>0.023</td>
<td>0.151</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Dgrants&lt;sub&gt;c&lt;/sub&gt;</td>
<td>0.081</td>
<td>0.273</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Dpatentbox&lt;sub&gt;c&lt;/sub&gt;</td>
<td>0.022</td>
<td>0.147</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Ddeduc&lt;sub&gt;c&lt;/sub&gt;</td>
<td>0.029</td>
<td>0.169</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Deatrrd&lt;sub&gt;c&lt;/sub&gt;</td>
<td>0.982</td>
<td>0.131</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(</td>
<td>lat_r</td>
<td>)</td>
<td>40.205</td>
<td>9.583</td>
</tr>
</tbody>
</table>

S = 5633
### Estimation Results: Marginal Effects

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>patents, (inv)</td>
<td>patents, (inv)</td>
<td>patents, (inv)</td>
<td>patents, (inv)</td>
<td>patents, (app)</td>
<td>patents, (app)</td>
<td>patents, (app)</td>
<td>patents, (app)</td>
</tr>
<tr>
<td>$\log(\tilde{L}_r)$</td>
<td>1.260***</td>
<td>1.287***</td>
<td>1.321***</td>
<td>1.315***</td>
<td>1.098***</td>
<td>1.160***</td>
<td>1.153***</td>
<td>1.186***</td>
</tr>
<tr>
<td></td>
<td>(0.070)</td>
<td>(0.038)</td>
<td>(0.062)</td>
<td>(0.043)</td>
<td>(0.036)</td>
<td>(0.058)</td>
<td>(0.034)</td>
<td>(0.038)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.036)</td>
<td>(0.058)</td>
<td>(0.034)</td>
<td>(0.038)</td>
</tr>
<tr>
<td>$D_{taxcredit_c}$</td>
<td>0.069</td>
<td>0.223</td>
<td>0.146</td>
<td>0.272</td>
<td>0.206</td>
<td>0.427</td>
<td>0.170</td>
<td>0.516</td>
</tr>
<tr>
<td></td>
<td>(0.438)</td>
<td>(0.426)</td>
<td>(0.501)</td>
<td>(0.476)</td>
<td>(0.391)</td>
<td>(0.372)</td>
<td>(0.415)</td>
<td>(0.427)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$D_{superd_c}$</td>
<td>0.160</td>
<td>-0.416</td>
<td>0.193</td>
<td>-1.609***</td>
<td>0.226</td>
<td>-0.306</td>
<td>-1.301*</td>
<td>-1.298**</td>
</tr>
<tr>
<td></td>
<td>(0.697)</td>
<td>(0.541)</td>
<td>(0.663)</td>
<td>(0.537)</td>
<td>(0.514)</td>
<td>(0.490)</td>
<td>(0.775)</td>
<td>(0.544)</td>
</tr>
<tr>
<td>$D_{taxholiday_c}$</td>
<td>2.451**</td>
<td>2.234***</td>
<td>1.394**</td>
<td>2.410***</td>
<td>3.317***</td>
<td>3.032***</td>
<td>2.853***</td>
<td>3.108***</td>
</tr>
<tr>
<td></td>
<td>(1.024)</td>
<td>(0.732)</td>
<td>(0.669)</td>
<td>(0.489)</td>
<td>(0.542)</td>
<td>(0.395)</td>
<td>(0.560)</td>
<td>(0.457)</td>
</tr>
<tr>
<td>$D_{grants_c}$</td>
<td>1.277***</td>
<td>1.297***</td>
<td>2.055</td>
<td>2.307</td>
<td>1.522***</td>
<td>1.498***</td>
<td>2.576</td>
<td>2.951</td>
</tr>
<tr>
<td></td>
<td>(0.430)</td>
<td>(0.396)</td>
<td>(2.008)</td>
<td>(2.100)</td>
<td>(0.375)</td>
<td>(0.361)</td>
<td>(2.187)</td>
<td>(2.387)</td>
</tr>
<tr>
<td>$D_{patentbox_c}$</td>
<td>-2.199**</td>
<td>-2.077***</td>
<td>-1.813***</td>
<td>-2.638***</td>
<td>-3.190***</td>
<td>-3.114***</td>
<td>-3.476***</td>
<td>-3.668***</td>
</tr>
<tr>
<td></td>
<td>(1.059)</td>
<td>(0.769)</td>
<td>(0.656)</td>
<td>(0.502)</td>
<td>(0.565)</td>
<td>(0.400)</td>
<td>(0.604)</td>
<td>(0.515)</td>
</tr>
<tr>
<td>$D_{deduc_c}$</td>
<td>0.102</td>
<td>0.272</td>
<td>0.130</td>
<td>1.134**</td>
<td>1.558*</td>
<td>0.178</td>
<td>1.582*</td>
<td>1.007**</td>
</tr>
<tr>
<td></td>
<td>(0.324)</td>
<td>(0.266)</td>
<td>(0.349)</td>
<td>(0.471)</td>
<td>(0.908)</td>
<td>(0.290)</td>
<td>(0.933)</td>
<td>(0.437)</td>
</tr>
<tr>
<td>$D_{eatrrd_c}$</td>
<td>1.775**</td>
<td>2.004***</td>
<td>1.962**</td>
<td>2.093***</td>
<td>-0.106</td>
<td>-0.093</td>
<td>0.093</td>
<td>-0.108</td>
</tr>
<tr>
<td></td>
<td>(0.775)</td>
<td>(0.720)</td>
<td>(0.784)</td>
<td>(0.751)</td>
<td>(0.574)</td>
<td>(0.549)</td>
<td>(0.581)</td>
<td>(0.571)</td>
</tr>
<tr>
<td></td>
<td>(1.051)</td>
<td>(0.745)</td>
<td>(0.935)</td>
<td>(0.771)</td>
<td>(0.607)</td>
<td>(0.788)</td>
<td>(0.589)</td>
<td>(0.601)</td>
</tr>
<tr>
<td>$\lnalpha$</td>
<td>0.946***</td>
<td>1.509***</td>
<td>0.858***</td>
<td>1.438***</td>
<td>1.570***</td>
<td>2.177***</td>
<td>1.463***</td>
<td>2.103***</td>
</tr>
<tr>
<td></td>
<td>(0.188)</td>
<td>(0.176)</td>
<td>(0.177)</td>
<td>(0.170)</td>
<td>(0.170)</td>
<td>(0.323)</td>
<td>(0.175)</td>
<td>(0.331)</td>
</tr>
<tr>
<td># obs</td>
<td>5633</td>
<td>5633</td>
<td>5633</td>
<td>5633</td>
<td>5633</td>
<td>5633</td>
<td>5633</td>
<td>5633</td>
</tr>
<tr>
<td></td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>overall fit</td>
<td>0.6434</td>
<td>0.7758</td>
<td>0.6471</td>
<td>0.5787</td>
<td>0.4732</td>
<td>0.6332</td>
<td>0.3922</td>
<td>0.3108</td>
</tr>
<tr>
<td>tax instruments fit</td>
<td>0.2091</td>
<td>0.2090</td>
<td>0.1057</td>
<td>0.1171</td>
<td>0.1259</td>
<td>0.1417</td>
<td>0.0431</td>
<td>0.0310</td>
</tr>
</tbody>
</table>
Kernel Density: Productivity Shifter $h_r$

Note: In the comparative statics we keep $h_r$ constant over all years.
Innovation and Patents in 2010: Data vs. Model ($\phi_r^{\xi} = \text{Patents}_r^{\tilde{\xi}}$)

![Scatter plot of Patents vs. $\phi_r$]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th>Patents $r &gt; 0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dep Var: $\text{Patents}_r^{\tilde{\xi}}$</td>
<td>$\text{Patents}_r &gt; 0$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>log($\phi_r$)</td>
<td>0.156***</td>
<td>(0.035)</td>
<td></td>
</tr>
<tr>
<td>cons</td>
<td>0.006*</td>
<td>(0.003)</td>
<td></td>
</tr>
<tr>
<td>#obs</td>
<td>4642</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Negative binominal regression

Egger and Püschel (ETH Zurich)
The Economic Geography of Innovation
December 4, 2017 26 / 52
Counterfactual Analysis
Counterfactual Experiments

We analyze key parameters (employment, welfare, productivity, innovation) in three different scenarios:

1. No R&D tax incentives \((h_r = 1, \ \forall \ r)\)
2. No R&D tax holidays
3. No R&D grants

<table>
<thead>
<tr>
<th>Tax Policy Instrument</th>
<th>Description</th>
<th>Countries (in 2005)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tax credits</td>
<td>Tax credits on R&amp;D investments</td>
<td>Austria, Canada, China, France, Ireland, Japan, Mexico, Netherlands, Norway, Portugal, South Korea, Spain, Taiwan, US, Venezuela.</td>
</tr>
<tr>
<td>Tax holidays</td>
<td>Tax holidays for firms with R&amp;D investments.</td>
<td>France, Malaysia, Singapore, Switzerland.</td>
</tr>
<tr>
<td>Grants</td>
<td>R&amp;D investments can benefit from grants</td>
<td>Germany, Hungary, Ireland, Israel.</td>
</tr>
<tr>
<td>Deductions</td>
<td>Any form of deductions on R&amp;D investments.</td>
<td>Australia, Belgium, Ireland, Japan, South Korea.</td>
</tr>
<tr>
<td>Super deductions</td>
<td>Super deductions of more than 100% for R&amp;D investments.</td>
<td>Australia, China, Czech Republic, Hungary, India, Malaysia, Malta, Puerto Rico, Singapore, UK.</td>
</tr>
<tr>
<td>EATR(_{R&amp;D})</td>
<td>Effective average tax rate is lower on returns on R&amp;D investments than on other investments.</td>
<td>114 of 213 countries in the data.</td>
</tr>
</tbody>
</table>

Kernel Densities of $h_r$ in Different Scenarios
1. The Evolution of R&D Incentives and Inequality Across Regions
Theil Index, World Population

Theil Index, World Utility

Baseline
No tax incentives
No tax holidays
No grants

Time

0 50 100 150 200 250 300

0.52 0.53 0.54 0.55 0.56 0.57 0.58

0.856 0.858 0.86 0.862 0.864 0.866 0.868 0.87
Evolution of World Inequality: Productivity & Innovation
Decomposition of Theil Index: Within Subgroup Welfare Inequality
Discussion: Inequality Analysis

- Overall the different tax instruments have only little impact on considered inequality aspects.

- While the distribution of world population/utility/innovation is no more (un)equal if R&D grants or R&D tax holidays were abandoned, world population/utility/innovation would be more equally distributed if no tax instruments at all were in place.

- On the other hand, the different tax instruments have a more distinct impact on the distribution of world productivity. Both, R&D grants and R&D tax holidays, decrease the level of inequality in world productivity.

- The decomposition of the Theil index allows for within-country comparisons, i.e., comparison between regions of the same country.

- The results suggest that countries experience an increase in welfare inequality between regions, if a tax instrument was abolished that they had in place (France: R&D tax holidays and Ireland/Germany: R&D grants)

- There are spillover effects from abolishing R&D tax incentives in neighboring economies: Germany’s welfare inequality would be lowest if R&D tax holidays were abandoned abroad.
2. R&D Tax Holidays, R&D Grants and Welfare Levels at $T=300$
Counterfactual Analysis

Welfare Change: Baseline vs. No R&D Tax Holidays in T=300

Regions w Tax Holidays

Regions w/o Tax Holidays

Area of symbol proportional to region’s observed population density in 2005
Welfare Change: Baseline vs. No R&D Tax Holidays, by Country with R&D Tax Holidays (T=300)
Discussion: R&D Tax Holidays

- Among those regions with R&D tax holidays, the majority experiences a drop in welfare from abandoning that instrument.
- There are regions which experience a welfare gain from abandoning R&D tax holidays.
- The country-specific analysis suggests that those regions are part of smaller economies, e.g., Singapore or Malaysia.
- There is only little correlation between amenities and the magnitude of the welfare change.
Counterfactual Analysis

Welfare Change: Baseline vs. No R&D Grants in T = 300

Regions w Grants

Regions w/o Grants

Area of symbol proportional to region’s observed population density in 2005.
Counterfactual Analysis

Welfare Change: Baseline vs. No R&D Grants, by Country with R&D Grants (T=300)

Size of symbol proportional to region's observed population density in 2005

Log(u_{r, No Grants}) - Log(u_{r, Baseline})
In all regions, independent of whether a R&D grants policy was in place, welfare declines when abandoning R&D grants.

As for tax holidays, the welfare loss is heterogeneous in regions where the policy instrument prevails.

The differences are well explained by a country effect – however, no indication that the size of the economy plays a role.
3. Welfare Change and Remoteness: R&D Tax Holidays, R&D Grants at T=300
The welfare change of the treated regions correlates with the remoteness of those regions (Corr. Tax holidays: 0.17, Corr. Grants: 0.12)
Innovation incentives are important policy instruments to attract mobile factors and enhance regional well-being.

Results suggest that innovation incentives have only little impact on reducing welfare inequalities.

However, there is evidence of spillover effects – Germany’s welfare inequality would be comparatively lowest if R&D tax holidays were abandoned in the neighborhood (such policy exists in France and Switzerland, among others).

Heterogeneous effects for different tax polices: R&D grants have a positive welfare effect on all regions, whereas R&D tax holidays only benefit those regions where the policy is in place.

The welfare change due to innovation incentives seems only weakly correlated with the economic attractiveness of a region (amenities), while remoteness is important.
Thank you!
Appendix

Amenity Distribution

- We substitute the indirect utility (9) into the first equilibrium condition (11) and solve for $a_{rt}$ as follows

\[
  a_{rt} = \left( \frac{G_r \bar{L}_{rt}}{L} \right)^\Omega \left[ \frac{\int_S (a_{kt} w_{kt})^{1/\Omega} (\int_S B_{jt} d{j})^{(1/\Omega\theta)} dk}{w_{rt} (\int_S B_{kt} dk)^{(1/\theta)}} \right]^{\Omega} \tag{19}
\]

- $B(\cdot)_t = \tau(\cdot)_t \bar{L}^\rho(\cdot)_t w(\cdot)_t h(\cdot)_t \zeta(\cdot)_s$

- $\rho = \alpha - ((1 - \mu - \gamma_1/\xi)\theta)$

Data

- $\bar{L}_{rt}$: Observed population density in 2005 (SEDAC).
- $w_{rt}$: Observed wages per capita in 2005 (G-Econ Project).
- $\tau_{rt}$: Initial efficiency distribution obtained through iterative process using the model structure and data on observed wages and population densities in 2005.
Assignment Strategy

- Some data that we use for estimation and simulation are on the $1^\circ \times 1^\circ$-cell level: trade costs, wages per capita, GDP per capita.
- Strategy to assign data to the regional level:
  1. $M : 1$ assignment: simple average of all cells falling in region $r$.
  2. $1 : M$ assignment: nearest cell within country border.
Assignment Strategy: Wages

1: $M$ assignment: wage levels are identical for regions that are assigned to the same 1° cell.

- We use night-light and population information (both 2005) to weight wages accordingly.

- Assumption:

  \[
  \frac{\text{light p/c in region } r}{\text{avg(light p/c } \forall \text{ regions of same cell})} = \frac{\text{wage p/c in region } r}{\text{avg(wage p/c } \forall \text{ regions of same cell})}
  \]

- Night light data is censored ($0 \leq \text{light} \leq 63$). We deal with the sum of all light pixels in a given region. Hence, we only know the lower bound.

- We run a tobit regression to predict the true night light values per region, $\text{sumlight}_r$:

  \[
  \text{sumlight}_r = \begin{cases} 
  0 & \text{if } \text{sumlight}_r^* \leq 0 \\
  \text{sumlight}_r^* & \text{if } \text{sumlight}_r^* > 0 
  \end{cases}
  \]

- We specify the latent variable $\text{sumlight}_r^*$ in a linear fashion as a function of the parameters of interest through

  \[
  \log(\text{sumlight}_r^*) = \alpha_1 \log(\text{wage}_r) + \alpha_2 \log(\text{pop}_r) + \alpha_3 \log(\text{area}_r) + V_r + \epsilon_r^{\text{light}}.
  \]

Note: We also included quadratic terms of all explanatory variables in $V_r$. 
Contrary to DNRH '17, we allow for intra-regional trade. Transport costs within a region are obtained by two strategies:

- If many cells fall within a region: Simple average of transport costs.
- If many regions get assigned to the same cell: We learn the exchange rate between fast marching transport costs $\zeta_{sk}$ and the great circle distance ($dist_{sk}$ in degrees).

\[
\log(\zeta_{sk}) = \alpha_0 + \alpha_1 \log(dist_{sk}) + \varepsilon_{sk}^{\zeta}
\]  

(20)

<table>
<thead>
<tr>
<th></th>
<th>$0 &lt; dist_{sk} \leq 3$</th>
<th>$3 &lt; dist_{sk} \leq 20$</th>
<th>$20 &lt; dist_{sk} \leq \text{max}(dist_{sk})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>log($dist_{sk}$)</td>
<td>1.021*** (0.003)</td>
<td>0.832*** (0.000)</td>
<td>0.219*** (0.000)</td>
</tr>
<tr>
<td>const</td>
<td>3.610*** (0.002)</td>
<td>3.886*** (0.001)</td>
<td>5.979*** (0.000)</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.284</td>
<td>0.285</td>
<td>0.091</td>
</tr>
<tr>
<td>#obs</td>
<td>419,580</td>
<td>13,228,282</td>
<td>276,969,394</td>
</tr>
</tbody>
</table>
Tariffs: We inflate the transport cost matrix by applied weighted tariffs for manufactured products according to WTO rules (WDI).

Linguistic proximity (LP): We inflate the transport cost matrix by an indicator that measures LP (Melitz and Toubal, 2014).

Impact on the results:

<table>
<thead>
<tr>
<th>Fast Marching</th>
<th>Fast Marching Tariffs &amp; LP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Total country-to-country imports to total sales</strong></td>
<td></td>
</tr>
<tr>
<td>t=1</td>
<td>0.0312</td>
</tr>
<tr>
<td>t=300</td>
<td>0.0762</td>
</tr>
<tr>
<td><strong>2. Total intra-regional trade to total sales</strong></td>
<td></td>
</tr>
<tr>
<td>t=1</td>
<td>0.6596</td>
</tr>
<tr>
<td>t=300</td>
<td>0.7303</td>
</tr>
<tr>
<td><strong>3. Correlation btw. estimated and observed population density</strong></td>
<td></td>
</tr>
<tr>
<td>levels 2010</td>
<td>0.9993</td>
</tr>
<tr>
<td>logs 2010</td>
<td>0.9996</td>
</tr>
<tr>
<td>levels diff 2010-2005</td>
<td>0.5551</td>
</tr>
<tr>
<td>logs diff 2010-2005</td>
<td>0.4446</td>
</tr>
</tbody>
</table>
Welfare vs. Productivity Change: R&D Tax Holidays and R&D Grants, by Groups of Regions (T=300)

Note: Productivity in the model is defined as $z_{rt} = (\tau_{rt} L_{rt})^{1/\theta}$