

Cattle, Steaks and Restaurants: Development Accounting when Space Matters

Péter Karádi* and Miklós Koren†

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Abstract

Productivity is much lower in poor countries than in rich ones (REFS). To understand the fundamental causes of productivity differences, it is important to identify the sectors in which these differences are greatest (REF). Several recent papers have studied the sectoral composition of productivity differences by using data on sector-level prices (REF). The main result is XXX. Intuitively, prices are XXX

We revisit the measurement of sectoral prices and sectoral productivity in a macro model where land and location play a role. A high price in one sector may simply reflect high rents accruing to a non-reproducible input, land. For example, the fact that restaurants are expensive in New York City has more to do with high rents, and may not imply that NYC restaurants are inefficient. Rents are, in turn, determined in general equilibrium, and may respond to demand for land in other activities, such as finance, culture and housing in the NYC example.

We build a multi-sector general equilibrium model. Each sector uses labor (or a composite of other spatially mobile inputs) and land. The location of sectors is determined in the canonical von Thünen city model. XXX DESCRIBE MODEL

Our model yields a simple spatial equilibrium in which agriculture (“cattle”) locates farthest away from the center, manufacturing (“steaks”) occupies a ring outside the center, and services (“restaurants”) are in a central circle.

There are two reasons why development accounting in our model is different from models without land. First, as some sectors are more land intensive, their prices may be more sensitive to rents. Because of this, conditional on productivity, agricultural prices will be relatively higher in rich countries. Second, because sectors endogenously choose locations, their price is also affected by the rent gradient: the speed with which rents decline in distance from the city center. Urban sectors will be relatively more expensive in countries where the rent gradient is higher.

*European Central Bank. E-mail: peter.karadi@ecb.int

†Central European University, IE-HAS and CEPR. E-mail: korenm@ceu.hu.

To quantify the importance of these two mechanisms, we calibrate our model to match the spatial distribution of economic activities in the U.S., and the share of sectors in each country. We then use the calibrated model to infer sector-level productivities for each country using data on relative prices (XX AND URBANIZATION)

Our main findings are as follows. XX

1 A model of industry location

1.1 Technology

Output in sector i at location z depends on employment and land used at that location,

$$Q_i(z) = A_i L_i(z)^{\beta_i} N_i(z)^{1-\beta_i}.$$

We take labor to be freely mobile within the country, land is in fixed supply in each location. The names “land” and “labor” are for the sake of convenience, these two factors correspond to spatially fixed and mobile factors, respectively, and we will calibrate them accordingly.

Sectors differ in their land shares β_i and Hicks neutral productivity shifter A_i .

All products are sold and consumed at a single location, the central business district. This is location $z = 0$, so that z indexes distance to the center.

1.2 Shipping

To ship a product to the center, one has to incur shipping costs. If a unit of product i leaves location z , only

$$e^{-\tau_i z}$$

units arrive at the center. This is akin to the iceberg assumption of fixed costs. Sectors also differ in the intensity of shipping costs τ_i .

1.3 Consumers

Consumers have Cobb–Douglas preferences across the three goods,

$$U = C_1^{\alpha_1} C_2^{\alpha_2} C_3^{\alpha_3}$$

1.4 Spatial structure

At each location z where industry i is active, the value marginal product of land and labor have equal rents and wages, respectively.

$$R(z) = \beta_i P_i e^{-\tau_i z} A_i \left(\frac{N_i(z)}{L_i(z)} \right)^{1-\beta_i} \tag{1}$$

$$W = (1 - \beta_i) P_i e^{-\tau_i z} A_i \left(\frac{N_i(z)}{L_i(z)} \right)^{-\beta_i} \tag{2}$$

Because labor is freely mobile, wages do not depend on location.

The labor-land ratio (employment density) can be expressed as

$$\frac{N_i(z)}{L_i(z)} = \frac{1 - \beta_i}{\beta_i} \frac{R(z)}{W}.$$

Substituting this into the FOC for land,

$$\begin{aligned} R(z) &= \beta_i P_i e^{-\tau_i z} A_i \left(\frac{1 - \beta_i}{\beta_i} \frac{R(z)}{W} \right)^{1 - \beta_i} \\ R(z)^{\beta_i} &= \beta_i^{\beta_i} (1 - \beta_i)^{1 - \beta_i} P_i e^{-\tau_i z} A_i W^{\beta_i - 1} \\ R(z) &= \beta_i (1 - \beta_i)^{1/\beta_i - 1} (P_i A_i)^{1/\beta_i} W^{1 - 1/\beta_i} e^{-\frac{\tau_i}{\beta_i} z} \end{aligned}$$

This pins down the gradient of the bid-rent curve. Substituting into the labor-land ratio,

$$\frac{N_i(z)}{L_i(z)} = (1 - \beta_i)^{1/\beta_i} \left(\frac{P_i A_i}{W} \right)^{1/\beta_i} e^{-\frac{\tau_i}{\beta_i} z}$$

gives us the employment gradient.

1.5 Aggregation across space

Value added per unit of land at consumer prices,

$$\frac{P_i Q_i(z)}{L_i(z)} = (1 - \beta_i)^{1/\beta_i - 1} (P_i A_i)^{1/\beta_i} W^{1 - 1/\beta_i} e^{-\frac{1 - \beta_i}{\beta_i} \tau_i z}.$$

The same at producer prices

$$\frac{e^{-\tau_i z} P_i Q_i(z)}{L_i(z)} = (1 - \beta_i)^{1/\beta_i - 1} (P_i A_i)^{1/\beta_i} W^{1 - 1/\beta_i} e^{-\frac{\tau_i}{\beta_i} z}.$$

Let

$$\tilde{z}_i = -\frac{\beta_i}{\tau_i} \ln \int_{z \in Z_i} \frac{L_i(z)}{L_i} e^{-\frac{\tau_i}{\beta_i} z} dz$$

denote the average distance of sector i to the center, where $L_i = \int_{z \in Z_i} L_i(z) dz$ is the total amount of land devoted to sector i . This definition ensures that the trade cost going to location \tilde{z}_i equals the land-weighted average trade cost across all sectoral locations,

$$e^{-\frac{\tau_i}{\beta_i} \tilde{z}_i} = \int_{z \in Z_i} \frac{L_i(z)}{L_i} e^{-\frac{\tau_i}{\beta_i} z} dz.$$

As we will see below, \tilde{z}_i is a sufficient statistic about sector location for aggregation purposes.
(XX THIS IS A TRICK OF THE MELITZ MODEL)

The the total supply of sector i at producer prices,

$$Y_i = (1 - \beta_i)^{1/\beta_i - 1} (P_i A_i)^{1/\beta_i} W^{1-1/\beta_i} L_i e^{-\frac{\tau_i}{\beta_i} \tilde{z}_i}.$$

Overall employment in the sector,

$$N_i = (1 - \beta_i)^{1/\beta_i} \left(\frac{P_i A_i}{W} \right)^{1/\beta_i} L_i e^{-\frac{\tau_i}{\beta_i} \tilde{z}_i},$$

so that we can express W/P_i as

$$\begin{aligned} \left(\frac{W}{P_i} \right)^{1/\beta_i} &= (1 - \beta_i)^{1/\beta_i} N_i^{-1} A_i^{1/\beta_i} L_i e^{-\frac{\tau_i}{\beta_i} \tilde{z}_i} \\ \frac{W}{P_i} &= (1 - \beta_i) N_i^{-\beta_i} A_i^{\beta_i} L_i e^{-\tau_i \tilde{z}_i} \\ \left(\frac{W}{P_i} \right)^{1-1/\beta_i} &= (1 - \beta_i)^{1-1/\beta_i} A_i^{1-1/\beta_i} N_i^{1-\beta_i} L_i^{\beta_i - 1} e^{\frac{1-\beta_i}{\beta_i} \tau_i \tilde{z}_i} \end{aligned}$$

1.6 Productivity measurement

Suppose physical output is measured as revenue at producer prices deflated by a common price index. We take the price index to be the consumer price (XX CHECK IF IT MATTERS).

$$\tilde{Q}_i(z) = \frac{e^{-\tau_i z} P_i Q_i(z)}{P_i}$$

We can write an aggregate output as

$$\tilde{Q}_i = (1 - \beta_i)^{1/\beta_i - 1} A_i^{1/\beta_i} \left(\frac{W}{P_i} \right)^{1-1/\beta_i} L_i e^{-\frac{\tau_i}{\beta_i} \tilde{z}_i}$$

which takes us to the aggregate production function

$$\tilde{Q}_i = A_i L_i^{\beta_i} N_i^{1-\beta_i} e^{-\tau_i \tilde{z}_i}.$$

Aggregate output is a Cobb–Douglas function of land and labor, adjusted with trade costs. The factor is smaller for sectors with large trade costs (τ_i) and sectors farther away from the city (larger \tilde{z}_i). Simply put, services will look unproductive in New York City relative to Budapest, because NYC is larger.

Output per worker

$$\frac{\tilde{Q}_i}{N_i} = \frac{1}{1 - \beta_i} \frac{W}{P_i}$$

We want to get rid of product prices in this formula and express them as a function of input costs

$$\frac{R_i}{W} = \beta_i (1 - \beta_i)^{1/\beta_i - 1} \left(\frac{P_i A_i}{W} \right)^{1/\beta_i} e^{-\frac{\tau_i}{\beta_i} \tilde{z}_i},$$

where R_i is the rent prevailing at location \tilde{z}_i (which is also equal to the average rent paid by the sector, as proven below)

$$\begin{aligned}
R(\tilde{z}_i) &= R(z_{i-1})e^{-\frac{\tau_i}{\beta_i}(\tilde{z}_i - z_{i-1})} \\
R_i &= \int_{z \in Z_i} \frac{L_i(z)}{L_i} R(z) dz = R(z_{i-1})e^{\frac{\tau_i}{\beta_i}z_{i-1}} \int_{z \in Z_i} \frac{L_i(z)}{L_i} e^{-\frac{\tau_i}{\beta_i}z} dz \\
\left(\frac{W}{P_i}\right)^{1/\beta_i} &= \beta_i(1 - \beta_i)^{1/\beta_i - 1} A_i^{1/\beta_i} \frac{W}{R_i} e^{-\frac{\tau_i}{\beta_i}\tilde{z}_i} \\
\frac{W}{P_i} &= \beta_i^{\beta_i}(1 - \beta_i)^{1 - \beta_i} A_i \left(\frac{W}{R_i}\right)^{\beta_i} e^{-\tau_i\tilde{z}_i}
\end{aligned}$$

so that output per worker can be written as

$$\frac{\tilde{Q}_i}{N_i} = \beta_i^{\beta_i}(1 - \beta_i)^{-\beta_i} A_i \left(\frac{W}{R_i}\right)^{\beta_i} e^{-\tau_i\tilde{z}_i}.$$

Log output per worker is

$$\tilde{q}_i - n_i = \beta_i \ln \beta_i + (1 - \beta_i) \ln(1 - \beta_i) + a_i + \beta_i(w - r_i) - \tau_i z_i$$

Conditional on true productivity a_i , measured productivity is lower in cities where rents are higher. The magnitude of this bias depends on the (direct and indirect) land share of the sector, β_i . Measured productivity is also lower whenever the sector locates far from the center (z_i is high). Interestingly, this bias does not depend on the land share. The intuition is that XX

The former bias will be bigger for rich countries, as rents tend to be more sensitive to per capita income than wages are. The latter bias will be bigger for rich and urbanized countries, where each urban sector takes up more space.

1.7 Development accounting

Inferring productivity from output per worker,

$$a_i = \tilde{a}_i + \gamma_i + \beta_i(r_i - w) + \tau_i z_i,$$

where $\tilde{a}_i = q_i - n_i$ is log measured productivity and $\gamma_i = -\beta_i \ln \beta_i - (1 - \beta_i) \ln(1 - \beta_i)$ is a sector-specific constant. This is our main equation for sector-level development accounting.

We are interested in how sectoral productivities are correlated with per capita income.

$$\frac{da_i}{dy_i} = \frac{d\tilde{a}_i}{dy_i} + \beta_i \left(\frac{dr_i}{dy_i} - \frac{dw}{dy_i} \right) + \tau_i \frac{dz_i}{dy_i}.$$

1.8 Spatial arbitrage

Competitive land markets ensure that each location goes to the highest bidder. The slope of the bid-rent gradient in sector i is τ_i/β_i . Suppose that this is the highest for services, lower for manufacturing, and lowest for agriculture.

Let z_i denote the outer edge of the land use of sector i . At such locations, both sector i and sector $i + 1$ have the same reservation rent:

$$\begin{aligned} R(z_i) &= \beta_i(1 - \beta_i)^{1/\beta_i-1}(P_i A_i)^{1/\beta_i} W^{1-1/\beta_i} e^{-\frac{\tau_i}{\beta_i} z_i} \\ R(z_i) &= \beta_{i+1}(1 - \beta_{i+1})^{1/\beta_{i+1}-1}(P_{i+1} A_{i+1})^{1/\beta_{i+1}} W^{1-1/\beta_{i+1}} e^{-\frac{\tau_{i+1}}{\beta_{i+1}} z_i} \end{aligned}$$

Substitute in the overall amount of value added,

$$R_i(z) = R_i e^{-\frac{\tau_i}{\beta_i}(z - \tilde{z}_i)}.$$

$$R_i = \frac{\beta_i Y_i}{L_i}$$

$$R_i(z) = \frac{\beta_i Y_i}{L_i} e^{-\frac{\tau_i}{\beta_i}(z - \tilde{z}_i)}.$$

At the location z_{i-1} where sectors i and $i - 1$ meet,

$$\frac{\beta_{i-1} Y_{i-1}}{L_{i-1}} e^{-\frac{\tau_{i-1}}{\beta_{i-1}}(z_{i-1} - \tilde{z}_{i-1})} = \frac{\beta_i Y_i}{L_i} e^{-\frac{\tau_i}{\beta_i}(z_{i-1} - \tilde{z}_i)}.$$

$$\Delta \ln \beta_i + \Delta y_i - \Delta l_i = \frac{\tau_i}{\beta_i}(z_{i-1} - \tilde{z}_i) - \frac{\tau_{i-1}}{\beta_{i-1}}(z_{i-1} - \tilde{z}_{i-1})$$

$$\Delta \ln \beta_i + \Delta y_i - \Delta l_i = \frac{\tau_{i-1}}{\beta_{i-1}} \tilde{z}_{i-1} - \frac{\tau_i}{\beta_i} \tilde{z}_i + \left(\frac{\tau_i}{\beta_i} - \frac{\tau_{i-1}}{\beta_{i-1}} \right) z_{i-1}$$

Let \underline{R} denote the rent prevailing beyond the urban fringe (we may want to make agriculture costless to trade). Then we can find the urban fringe as the location z_2 such that $R_2(z_2) = \underline{R}$.

Agricultural rent is

$$\underline{R} = \frac{\beta_3 Y_3}{\int_{z_2}^{\tilde{z}} L(s) ds}$$

$$\frac{\beta_3 Y_3}{\int_{z_2}^{\tilde{z}} L(s) ds} = \frac{\beta_2 Y_2}{\Lambda_2(z_2) - \Lambda_2(z_1)} e^{-\frac{\tau_2}{\beta_2} z_2}$$

$$\frac{\tau_2}{\beta_2} z_2 = \ln \beta_2 - \ln \beta_3 + y_2 - y_3 + \ln \left[\int_{z_2}^{\tilde{z}} L(s) ds \right] - \ln [\Lambda_2(z_2) - \Lambda_2(z_1)]$$

The services-manufacturing barrier,

$$\frac{\beta_1 Y_1}{\Lambda_1(z_1)} e^{-\frac{\tau_1}{\beta_1} z_1} = \frac{\beta_2 Y_2}{\Lambda_2(z_2) - \Lambda_2(z_1)} e^{-\frac{\tau_2}{\beta_2} z_1}$$

$$e^{\left(\frac{\tau_1}{\beta_1} - \frac{\tau_2}{\beta_2}\right)z_1} = \frac{\beta_1 Y_1}{\beta_2 Y_2} \frac{\Lambda_2(z_2) - \Lambda_2(z_1)}{\Lambda_1(z_1)}$$

The following two equations implicitly define the two barriers z_1 and z_2 .

$$\frac{\beta_1 Y_1}{\beta_2 Y_2} = e^{\left(\frac{\tau_1}{\beta_1} - \frac{\tau_2}{\beta_2}\right)z_1} \frac{\Lambda_1(z_1)}{\Lambda_2(z_2) - \Lambda_2(z_1)} \quad (3)$$

$$\frac{\beta_2 Y_2}{\beta_3 Y_3} = e^{\frac{\tau_2}{\beta_2} z_2} \frac{\Lambda_2(z_2) - \Lambda_2(z_1)}{\int_{z_2}^{\bar{z}} L(s) ds} \quad (4)$$

2 Data and calibration

2.1 Variation across countries

Countries differ in Hicks-neutral productivities A_i , their urban fringe z_3 and their demand parameters α_i . Each country has the same land share within sectors β_i and the same shipping cost τ_i .

We allow for sector-specific differences in productivity, which are the key object of interest in multi-sector development accounting. The urban fringe may also vary with country area and its degree of urbanization and we calibrate it below. Demand parameters are allowed to vary to allow different countries to have different expenditure shares in agriculture, manufacturing and services. XX TALK MORE ABOUT STRUCTURAL CHG

2.2 Calibration

We calibrate sectoral land shares (β_i) using US data. Our aim is to capture the share of immobile factors in production. These come from two sources: (i) the direct use of land in production and (ii) the land-rent paid by workers. We calibrate the direct use of land in sectoral production using US factor income share estimates of Herrendorf and Valentinyi (2008). The first two columns of table XX show their estimates for land and labor shares across sectors.

Our land-rent share in labor estimate is a product of the US aggregate rent-share in consumption expenditure reported by the BLS (30%) and the average land-share of US house prices between 1984-1998 estimated by Davis and Palumbo (2008) (36%). We multiply this product by the labor shares, and add this product to the direct land use to obtain our land share estimate.

2.3 Sector gradients

We use the 2010 ZIP Business Patterns of the U.S. Census to determine the location of sectors in the United States. We use this to calibrate transportation costs and XX.

The ZIP Business Patterns contains the number of establishments in employment size categories in each ZIP code for each 6-digit NAICS code. We merge NAICS codes into agriculture, manufacturing and services as follows. XX TO DO.

| Factor shares | Direct land | Labor | Indirect land | Overall land share β_i |
|---------------|-------------|-------|---------------|------------------------------|
| Agriculture | 0.18 | 0.46 | 0.05 | 0.23 |
| Manufacturing | 0.03 | 0.67 | 0.07 | 0.10 |
| Services | 0.06 | 0.66 | 0.07 | 0.13 |

Land and Labor shares are estimates of Herrendorf and Valentinyi (2008). Land share in labor is the product of rent-share in US consumption expenditures, the average land-share of US house prices between 1984-1998 estimated by Davis and Palumbo (2008) and the labor shares. Our land share estimates are the sum of direct land share and the indirect land share through labor.

To map the model into the data, we need to specify how far each ZIP code is from the city center. We take Urbanized Areas (UAs) as independent monocentric cities, and we assign the central point to the business or administrative center of the first-mentioned city in the UA, as given by Yahoo Maps. For example, the center of “New York–Newark, NY-NJ-CT Urbanized Area” is the corner of Broadway and Chamber St in downtown Manhattan, whereas the center of “Boston, MA–NH-RI Urbanized Area” is 1 Boston Pl.

We calculate the distance of each ZIP code to business center of the nearest UA.

According to the model XX, the employment density of sector i in location z proportional to the rent-wage ratio. When industry i demands positive land in the neighborhood of z , then the rent gradient is proportional to $e^{-\tau_i z}$. We can use this observation to estimate τ_i .

$$\frac{d \ln n(z)/l(z)}{dz} = \frac{d \ln r(z)}{dz} = -\tau_i.$$

Let n_{izc} be the employment of industry i in ZIP code z , belonging to city (MSA) c . (Note that this employment can, and very often will be zero.) We denote the land area of ZIP code z by l_z .

$$\frac{n_{izc}}{l_z} = e^{\mu_c + \nu_i - \tau_i d(z,c)} \quad (5)$$

The city fixed effect captures variation in rents and wages in the MSA, the sector fixed effect captures variation in land and labor intensity across sectors. XX WE MAY NEED CITY*SECTOR FEs The key parameter of interest is τ , which captures how fast employment declines with distance to the center.

We estimate (??) by a Poisson regression which ensures that the equation holds in expectation, and permits estimation even when $n_{izc} = 0$, which is often the case. The estimates of τ_i in the three sectors are below. XX TO DO

XX TABLE HERE

The three columns report the estimates for agriculture, manufacturing and services, respectively. The estimated coefficients can be interpreted as follows. The employment density gradient of agriculture is inverted, reflecting the fact that most agricultural activity is carried out away from the cities.

2.4 Sector locations

We calibrate τ so as to match the location of sectors in the U.S. We use the Zip Business Patterns data (XX COPY FROM ABOVE) to calculate the employment-weighted median distance of each sector to the center of the MSA.

Figure XX shows the empirical distribution of distance across the three sectors. While there is certainly a wide range of distances for each sector, and the location of sectors overlaps, there is also a clear location shift visible: the typical agricultural employee is farther away than the typical industry employee, who is, in turn, farther away than service employees.

Table XX reports the median distance of each sector to the city center. Services are closest with 15.9km, manufacturing are 20.2km, whereas agriculture is 38.5km away from the center, as weighted by employment.

$$\frac{\int_0^z Y_1(s)ds}{\int_0^{z_1} Y_1(s)ds} = \frac{\Lambda_1(z)}{\Lambda_1(z_1)}$$

2.5 The urban fringe