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INVESTMENT NETWORKS AND REGIONAL INDUSTRIAL POLICY

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Investment Networks and Regional Industrial Policy

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Abstract

We show how efficiency criteria for granting sector-targeted subsidies change when subsidies are partially financed by resources originating outside the local economy, using a model of production and investment networks with market imperfections. We then apply the model to analyze the sector-targeted tax incentives administered by SUDENE in Brazil's Northeast region in 2023. We find that these incentives increase regional income by 0.4%. This effect could be further enhanced by expanding the set of eligible sectors or by reallocating the existing amount of tax expenditures across sectors.

Keywords: Regional Industrial Policy, Production Networks, Investment Networks, Input-Output Analysis, Tax Incentives

JEL Classification: C67, D50, E22, H25, O25, R13

1 Introduction

How is the cost-benefit assessment of industrial policy affected when sector-targeted benefits are partially financed by resources originating outside a regional economy? We address this question using a model of production and investment networks with market imperfections.

Liu (2019) shows that sector-targeted subsidies are efficient in economies where price distortions arising from market imperfections are amplified through the network of input-output linkages across sectors.

In this paper, we show how the sector selection criterion proposed by Liu (2019) is modified when external transfers finance a share of local government expenditures and subsidies. We then apply the model to analyze sector-targeted tax incentives in Brazil's Northeast region administered by the Superintendency for the Development of the Northeast (SUDENE).

Our empirical analysis yields three main results. First, from the perspective of Brazil's Northeast region, it is efficient to expand the set of eligible sectors. Second, SUDENE's tax incentives increase regional income by approximately 0.4%. Third, in a counterfactual exercise

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in which the current amount of SUDENE tax expenditures is reallocated across sectors according to the priority ranking implied by the model, the increase in regional income rises to 0.72%.

The model extends the analysis of Liu (2019) by incorporating investment networks, following Martinez and Orrillo (2026). We treat investment goods as a type of intermediate input, abstracting from capital accumulation effects, as in Dix-Carneiro and Traiberman (2023). Our paper is also related to the literature on quantitative spatial models, surveyed by Redding and Rossi-Hansberg (2017). Kleinman et al. (2023) incorporate capital accumulation into spatial models, while Casal and Caunedo (2026) discuss the role of investment networks in explaining regional differences in economic development. Finally, we contribute to the empirical literature on SUDENE by providing a quantitative general equilibrium evaluation of its tax incentives. Existing studies rely primarily on microeconometric methods, including Carneiro et al. (2024), who find positive effects on formal employment among beneficiary firms, and Oliveira et al. (2026), who examine the effects of multiple regional development policy instruments in Brazil's Northeast.

2 Model

The economy has N sectors, indexed by $j = 1, \ldots, N$, that produce intermediate and investment goods.[1] The production function is given by

$$Q_j = z_j F_j\left(L_j,\ \{M_{ij}\}_{i=1}^{N},\ \{X_{ij}\}_{i=1}^{N}\right), \tag{1}$$

and, under perfect competition, firms solve the following cost minimization problem:

$$\begin{aligned} P_j &= \min_{L_j, \{M_{ij}\}, \{X_{ij}\}} C_j \qquad \text{s.t.} \quad z_j F_j(L_j, \{M_{ij}\}, \{X_{ij}\}) \geq 1, \\ \text{where} \quad C_j &= \sum_{i=1}^{N} \left(1 - \tau_{ij} + \chi_{ij}\right) P_i \left(M_{ij} + X_{ij}\right) + W L_j, \end{aligned} \tag{2}$$

where Q_j is the output of the representative firm in sector j, z_j is total factor productivity, L_j is a fixed production factor, such as labor, M_{ij} denotes intermediate inputs produced by sector i and purchased by sector j, X_{ij} denotes investment goods produced by sector i and purchased by sector j, P_j is the price of the good produced by sector j, W is the price of the production factor, $\chi_{ij} \geq 0$ represents price distortions arising from market imperfections, and τ_{ij} denotes sector-targeted government subsidies. The production function F_j is continuously differentiable, increasing, concave in all its arguments, and exhibits constant returns to scale.

In addition to sales as intermediate inputs or investment goods, a share Y_i of each sector's output is allocated to final demand, as expressed by the feasibility constraint for good i:

$$Q_i = Y_i + \sum_{j=1}^{N} M_{ij} + \sum_{j=1}^{N} X_{ij}. \tag{3}$$

Final-good producers purchase Y_i, for $i = 1, \ldots, N$, and produce the aggregate final good

[1] Throughout the paper, we typically use index j when referring to a sector as a purchaser of inputs, and index i when referring to a sector as a supplier of goods.

Y^G. Their production function and cost minimization problem are given by:

$$Y^G = \mathcal{F}(Y_1, \cdots, Y_N), \tag{4}$$

$$1 = \min_{\{Y_i\}_{i=1}^N} \sum_{i=1}^{N} P_i Y_i \qquad \text{s.t.} \quad \mathcal{F}(Y_1, \cdots, Y_N) = 1, \tag{5}$$

where the price of the final good is normalized to one, and the production function $\mathcal{F}$ satisfies the same properties as the production functions F_j.

The final good is used for private consumption C, public consumption G, and to compensate for the utility loss Π borne by the recipients of quasi-rents. This utility loss may represent, for example, monitoring costs incurred by lenders in an economy with incomplete markets. Following Liu (2019), we assume that the monetary value of this deadweight loss is equal to the value of quasi-rents, so that market imperfections do not generate welfare gains for any agent in the economy. Thus,

$$Y^G = Y + \Pi, \tag{6}$$

where

$$Y = C + G, \tag{7}$$

$$\Pi = \sum_{j=1}^{N} \sum_{i=1}^{N} \chi_{ij} P_i \left(M_{ij} + X_{ij}\right). \tag{8}$$

where Y is the income measure used throughout the analysis, defined as the sum of private and public consumption, which also corresponds to the households' welfare measure.

The government grants total subsidies S_j to each sector and total subsidies S to all firms:

$$S = \sum_{j=1}^{N} S_j, \quad \text{where} \quad S_j = \sum_{i=1}^{N} \tau_{ij} P_i \left(M_{ij} + X_{ij}\right). \tag{9}$$

In addition, the government spends on public goods G and finances its expenditures by levying lump-sum taxes T on households, subject to the following budget constraint:

$$T = \eta \left(G + S\right). \tag{10}$$

where $\eta \in (0, 1]$.

The parameter η denotes the fraction of public expenditures and subsidies financed by taxes paid by residents of the region. We assume that a fixed fraction $(1-\eta)$ of the local government's budget is financed by transfers from outside the region.[2]

Households allocate factor income WL between private consumption and lump-sum tax payments:

$$C + T = WL. \tag{11}$$

Combining the previous equations, aggregate income can be written as:

$$Y = WL + (1 - \eta) G - \eta S. \tag{12}$$

[2] As in Liu (2019), we abstract from the distortionary effects of taxation and assume lump-sum taxes. Allowing for distortionary taxation would introduce an additional welfare cost of locally financed subsidies and could modify the quantitative policy trade-offs.

That is, aggregate income equals factor income plus the share of public expenditures financed by external transfers, minus the share of subsidies financed through local taxation.

Next, we present the equilibrium concept, production network measures, and the objects required to analyze the efficiency of sector-targeted subsidies.

Definition 1 (Equilibrium)**.** *Given the production functions* $\{F_j\}_{j=1}^N$ *and* $\mathcal{F}$*, productivities* $\{z_j\}_{j=1}^N$*, market imperfections* $\{\chi_{ij}\}_{i,j=1}^N$*, subsidies* $\{\tau_{ij}\}_{i,j=1}^N$*, labor endowment* L*, public consumption* G*, and the fraction* η *of the local government's budget financed by local taxes, an equilibrium is the collection of prices* $\{P_j\}_{j=1}^N$ *and* W*, allocations* $\{Q_j, L_j, M_{ij}, X_{ij}, Y_i, Y^G, C\}$*, taxes* T*, and deadweight losses* Π*, such that:*

i) Intermediate-good producers minimize costs according to (2)*, and final-good producers minimize costs according to* (5)*;*

ii) The government and household budget constraints, (10) *and* (11)*, are satisfied;*

iii) Markets clear: the labor market, $L = \sum_{j=1}^N L_j$*, final goods in* (6)*, and the market for each intermediate good* i*, according to* (3)*.*

Definition 2 (Production Network Measures)**.** *We define the following vectors and matrices for supplying sectors* i *and purchasing sectors* j *connected by production and investment networks:*

i) Final demand share of sector i*:*

$$\beta = [\beta_i]_{N\times 1}, \qquad \text{where} \quad \beta_i = \frac{P_i Y_i}{\sum_k P_k Y_k}.$$

ii) Share of sector j *in factor income:*

$$\theta^L = [\theta_j^L]_{N\times 1}, \qquad \text{where} \quad \theta_j^L = \frac{W L_j}{WL}.$$

iii) Input expenditure shares in the gross output of sector j*:*

$$\Omega^M = [\omega_{ij}^M]_{N\times N}, \qquad \Omega^X = [\omega_{ij}^X]_{N\times N}, \qquad \omega_L = [\omega_{Lj}]_{N\times 1},$$
$$\text{where} \quad \omega_{ij}^M = \frac{P_i M_{ij}}{P_j Q_j}, \quad \omega_{ij}^X = \frac{P_i X_{ij}}{P_j Q_j}, \quad \text{and} \quad \omega_{Lj} = \frac{W L_j}{P_j Q_j}.$$

iv) Production elasticities of sector j *with respect to its inputs:*

$$\Sigma^M = [\sigma_{ij}^M]_{N\times N}, \qquad \Sigma^X = [\sigma_{ij}^X]_{N\times N}, \qquad \sigma_L = [\sigma_{Lj}]_{N\times 1},$$
$$\text{where} \quad \sigma_{ij}^M = \frac{\partial \ln F_j(L_j, \{M_{ij}\}_{i=1}^N, \{X_{ij}\}_{i=1}^N)}{\partial \ln M_{ij}}, \quad \sigma_{ij}^X = \frac{\partial \ln F_j(L_j, \{M_{ij}\}_{i=1}^N, \{X_{ij}\}_{i=1}^N)}{\partial \ln X_{ij}},$$
$$\text{and} \quad \sigma_{Lj} = \frac{\partial \ln F_j(L_j, \{M_{ij}\}_{i=1}^N, \{X_{ij}\}_{i=1}^N)}{\partial \ln L_j}, \quad \text{with} \quad \sum_{i=1}^N \sigma_{ij}^M + \sum_{i=1}^N \sigma_{ij}^X + \sigma_{Lj} = 1,$$

since the elasticities sum to one because F_j *exhibits constant returns to scale.*

v) Shares in the composition of demand for the output of sector i:

$$\Theta^M = [\theta^M_{ij}]_{N\times N}, \qquad \Theta^X = [\theta^X_{ij}]_{N\times N}, \quad \theta^F = [\theta^F_i]_{N\times 1},$$

$$\text{were} \quad \theta^M_{ij} = \frac{M_{ij}}{Q_i}, \quad \theta^X_{ij} = \frac{X_{ij}}{Q_i}, \quad \text{and} \quad \theta^F_i = \frac{Y_i}{Q_i}, \quad \text{with} \quad \theta^F_i + \sum_{j=1}^{N} \theta^M_{ij} + \sum_{j=1}^{N} \theta^X_{ij} = 1.$$

Definition 3 (Distortion Centrality)**.** *The distortion centrality of sector j is defined as:*

$$\xi_j = \frac{\mu_j}{\gamma_j},$$

where μ_j and γ_j denote sector j's influence and Domar weight, respectively:

$$\mu = [I - (\Sigma^M + \Sigma^X)]^{-1} \cdot \beta, \quad \text{where} \quad \mu = [\mu_j]_{N\times 1}, \quad \text{and} \quad \gamma_j = \frac{P_j Q_j}{WL}.$$

The following propositions present our theoretical results. They apply to the introduction of sector-targeted subsidies in an economy without policy interventions, that is, starting from an initial equilibrium in which $\tau_{ij} = 0$ for all sectors. Therefore, when applying these results to an economy in which such subsidies already exist, they should be interpreted as approximations to the marginal gains or losses generated by the policy.

Proposition 1 shows the effect of introducing a tax subsidy τ_{ij} on regional income Y. The gain from promoting sector j is represented by μ_j, which depends on the sector's linkage effects through the production network. The cost increases with γ_j, a measure of the sector's relative size in the economy, since tax expenditures are larger when subsidies are directed toward sectors with a larger share of aggregate output.

Proposition 1. *In an economy without policy interventions ($\tau = \mathbf{0}$), the marginal effect of a tax subsidy τ_{ij} on income Y is given by*

$$\left.\frac{d \ln Y}{d\tau_{ij}}\right|_{\tau=\mathbf{0}} = \lambda \left(\omega^M_{ij} + \omega^X_{ij}\right)\left(\mu_j - \eta\, \gamma_j\right), \tag{13}$$

where λ is defined as

$$\lambda = \left.\frac{WL}{Y}\right|_{\tau=\mathbf{0}} = \frac{WL}{WL + (1-\eta)G}. \tag{14}$$

The novel elements introduced in this paper are the effects of the variables η and λ, both of which are equal to one in the model of Liu (2019). The smaller the share η of the local government's total budget financed by local taxes, the lower the welfare cost of granting a subsidy for residents of the economy. The term $\lambda(\omega^M_{ij} + \omega^X_{ij})$ scales the overall effect, whether positive or negative.

Proposition 2 next shows the social value of granting a subsidy, measured as the ratio between the marginal welfare gain and the marginal welfare loss, under the assumption that tax subsidies are financed either by a reduction in public consumption or by an increase in taxation.

Proposition 2. *The social value of subsidies in an economy without policy interventions ($\tau = \mathbf{0}$) is, when they are financed by a reduction in public consumption G holding T fixed,*

$$-\left.\frac{dC/d\tau_{ij}}{dG/d\tau_{ij}}\right|_{\tau=\mathbf{0},\, T \text{ fixed}} = \xi_j, \tag{15}$$

and, when they are financed by an increase in taxes T holding G fixed,

$$\left.\frac{dC/d\tau_{ij}}{dT/d\tau_{ij}}\right|_{\tau=\mathbf{0},\, G\,fixed} = \frac{\xi_j}{\eta} - 1. \tag{16}$$

The first result in Proposition 2 indicates that distortion centrality ξ_j measures the social value of promoting sector j when the policy is financed through a reduction in public consumption. According to the second result, the same measure also provides the priority ranking of sectors recommended by the theory when subsidies are financed through an increase in local taxation. In expression (16), distortion centrality ξ_j is divided by η and expressed as the deviation from the mean value of ξ_j, which is equal to one by construction. Comparing this expression with the government budget constraint in (10), we note that increases in subsidies S financed by reductions in G are unaffected by the value of η. However, if subsidies are financed through taxation, the required change in T depends on η.

Finally, Proposition 3 shows the aggregate effect on regional income of simultaneously introducing subsidies across multiple sectors.

Proposition 3. *The aggregate effect of simultaneously introducing a set of tax subsidies τ_{ij}, with $i, j = 1, \ldots, N$, in an economy without policy interventions ($\tau = \mathbf{0}$) is given by*

$$\Delta \ln Y \approx \sum_{j=1}^{N}\sum_{i=1}^{N} \left.\frac{d\ln Y}{d\tau_{ij}}\right|_{\tau=\mathbf{0}} \tau_{ij} = \lambda \sum_{j=1}^{N} \theta_j^L (\xi_j - \eta) s_j, \tag{17}$$

where $s_j = S_j/WL_j$ denotes subsidy expenditures relative to the value added of sector j.

Equation (17) shows, consistently with the previous propositions, that the effect of subsidies directed toward sector j on aggregate income is positive whenever distortion centrality ξ_j, defined as the ratio between influence μ_j and Domar weight γ_j, exceeds η. In addition, for a given total amount of subsidy expenditures, the aggregate impact is greater when subsidies are allocated to sectors with higher values of ξ_j.

3 Application

We illustrate the framework using the sector-targeted tax incentives administered by the Superintendency for the Development of the Northeast (SUDENE), the federal development agency for Brazil's Northeast region. The Northeast has the lowest per capita GDP among Brazil's five major regions, equivalent to 51% of the national average in 2022.[3] Originally established in 1959 and reestablished in 2007 after a period of discontinuation, SUDENE administers tax incentives available to firms undertaking projects in priority sectors. The main incentive is a 75% reduction in corporate income tax (IRPJ) liability, available to firms undertaking projects in sectors designated as priorities by Decree No. 4,213/2002. In 2023, this incentive accounted for 96% of SUDENE tax expenditures reported in the Brazilian Federal Revenue Service's Tax Expenditure Report (RFB, 2026).

SUDENE's jurisdiction covers the nine states of Brazil's Northeast region, as well as parts of the states of Minas Gerais and Espírito Santo. Since the datasets used in this paper take states

[3] Authors' calculation based on regional GDP from *Regional Accounts of Brazil* (IBGE, 2025) and population data from the 2022 Population Census (IBGE, 2023).

as the basic geographical unit, we approximate SUDENE's area of operation by considering only the nine Northeastern states.[4]

First, we compute the distortion centrality measure for each sector of the Northeastern economy and compare the resulting ranking with SUDENE's list of priority sectors. Second, we simulate the effect of introducing SUDENE's tax expenditures on regional income relative to an economy without policy interventions. Finally, we simulate a counterfactual scenario in which the same amount of tax expenditures is reallocated across sectors according to the priority ranking recommended by the theory.

To compute the sectoral distortion centrality measure ξ_i, we use a result corresponding to Proposition 4 of Liu (2019) in the version that incorporates investment networks. Analogously to Proposition 6 of Martinez and Orrillo (2026), which also applies to the model developed in this paper, the vector of sectoral distortion centrality, $\xi = [\xi_i]_{N\times 1}$, can be computed as

$$\xi = \frac{1}{\bar{\delta}} \left[I - \mathcal{D} \circ (\Theta^M + \Theta^X) \right]^{-1} \cdot \theta^F, \tag{18}$$

where $\mathcal{D} = [1 + \chi_{ij}]_{N\times N}$ is the matrix of market imperfections, the symbol $\circ$ denotes the Hadamard (element-by-element) product, and the scalar $\bar{\delta} = Y^G/WL$ is obtained from

$$\bar{\delta} = (\theta^L)' \cdot \left[I - \mathcal{D} \circ (\Theta^M + \Theta^X) \right]^{-1} \cdot \theta^F. \tag{19}$$

Table 1 summarizes the data sources used to compute sectoral distortion centrality ξ_i according to Eqs. (18) and (19).

Table 1: Moments for computing distortion centrality.

Moments	**Targets**	**Data**
$\theta_i^L = \frac{WL_i}{WL}$	$\frac{\text{Value added of sector } i}{\text{GDP}}$	2019 Northeast regional input-output table, use table at purchasers' prices
$\theta_j^F = \frac{Y_j}{Q_j}$	$\frac{\text{Final demand of sector } j}{\text{Total supply of sector } j}$	2019 Northeast regional input-output table, domestic and imported use table at basic prices
$\theta_{ij}^M = \frac{M_{ij}}{Q_j}$	$\frac{\text{Intermediate inputs from } j \text{ to } i}{\text{Total supply of sector } j}$	2019 Northeast regional input-output table, domestic and imported use table at basic prices
$\theta_{ij}^X = \frac{X_{ij}}{Q_j}$	$\frac{\text{Investment goods from } j \text{ to } i}{\text{Total supply of sector } j}$	2019 Northeast regional capital flows table
χ_{ij}	Average markup of manufacturing firms	As estimated by Cavalcante (2022) using the methodology of De Loecker and Warzynski (2012).

Source: Authors' elaboration.

For the moments θ_i^L, θ_i^F, and θ_{ij}^M, we use a 67-sector regional input-output table for Brazil's Northeast for 2019. This table is constructed from the 2019 Interregional Input-Output Table for Brazil of Haddad et al. (2025), which is disaggregated by Brazilian federative unit. We

[4]The Northeastern states are Alagoas (AL), Bahia (BA), Ceará (CE), Maranhão (MA), Paraíba (PB), Pernambuco (PE), Piauí (PI), Rio Grande do Norte (RN), and Sergipe (SE).

aggregate the tables corresponding to the nine Northeastern states.[5]

We construct a 67-sector regional capital flows table for Brazil's Northeast for 2019 to compute the values of θ_{ij}^{X}. The table is obtained using a modified biproportional RAS algorithm that reconciles the vector of gross fixed capital formation from the regional input-output table with information from the national capital flows table of Miguez and Freitas (2021) and the national input-output table of Alves-Passoni and Freitas (2023).

For market imperfections χ_{ij}, we use a common value of 1.24, corresponding to the average markup of Brazilian manufacturing firms estimated by Cavalcante (2022). These estimates are based on microdata from IBGE's Annual Industrial Survey (PIA) for the period 2000–2016, following the methodology of De Loecker and Warzynski (2012). Among the alternative measures of market imperfections considered by Liu (2019), the author argues that the methodology of De Loecker and Warzynski (2012) provides the most comprehensive measure. This is because the resulting markups are estimates of the gap between prices and marginal costs, regardless of the specific market imperfection that gives rise to the price distortion.

Figure 1 reports the distortion centrality values ξ_i by sector, highlighting the sectors that include activities supported by SUDENE tax incentives. The sectors are ordered according to their distortion centrality values, which determine the priority ranking recommended by the theory for granting sector-targeted subsidies in the Northeastern economy. The complete list of sector labels and their corresponding distortion centrality values is reported in Appendix B. The appendix also identifies the sectors classified as eligible for SUDENE tax incentives, corresponding to the priority activities listed in Decree No. 4,213/2002.[6]

Figure 1 includes two horizontal reference lines. The first, shown as a dotted line at $\bar{\xi} = 1$, indicates the weighted average distortion centrality across sectors, where the weights are given by each sector's share of factor income. By construction of the model, this average is equal to one. The second, shown as a dashed line, corresponds to the value of η, the fraction of government expenditures financed by taxes collected within the region. In the absence of transfers from outside the region, when $\eta = \lambda = 1$, the criterion recommended by the theory for promoting a sector is whether its distortion centrality lies above or below one, represented by the first reference line. When $\eta < 1$, it is efficient from the region's perspective to promote all sectors with $\xi_j > \eta$.

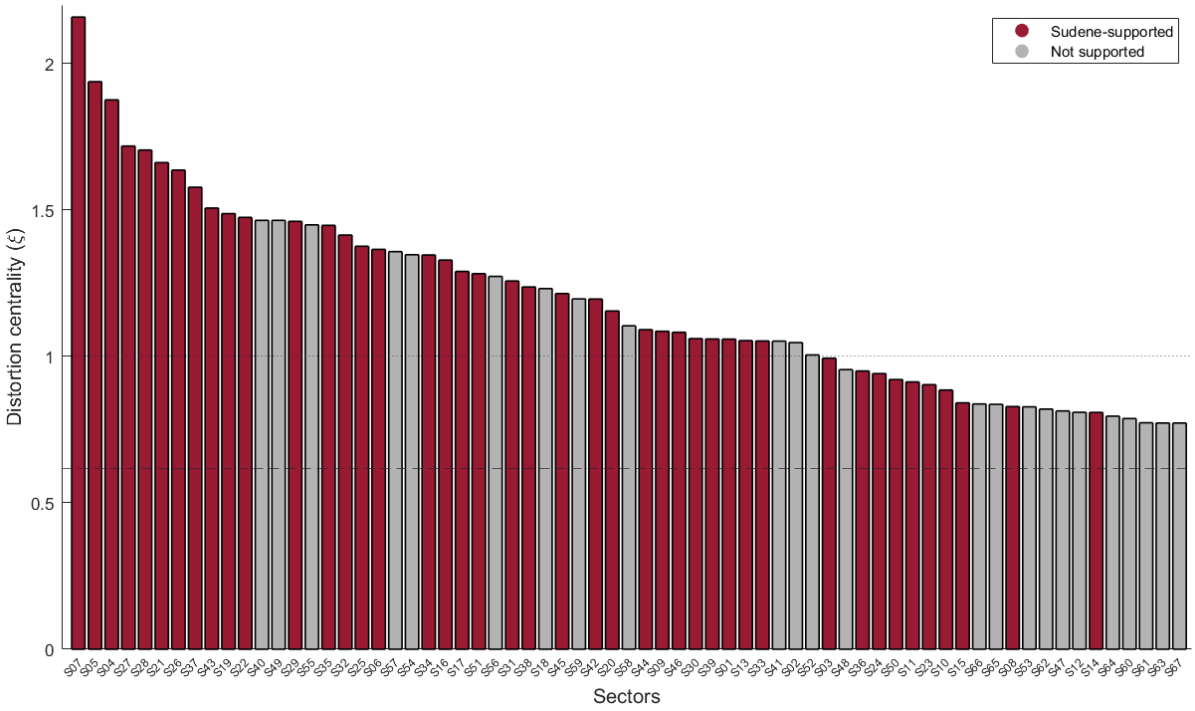
The second horizontal reference line, shown as a dashed line, corresponds to $\eta = 0.62$, the fraction of government expenditures financed by taxes collected within the region. From Eq. (10), we obtain η by noting that the net transfer of resources from the rest of Brazil to the Northeast, denoted by E, satisfies $E = (1 - \eta)(G + S)$. Solving for η, we combine estimates of net transfers to the Northeastern states for 2022 from Monteiro et al. (2023), government consumption in the Northeastern states from the 2019 Interregional Input-Output Table of Haddad et al. (2025), total tax expenditures in the Northeast for 2023 from the Brazilian Federal Revenue Service (RFB, 2026), and regional GDP from the *Regional Accounts of Brazil*. To harmonize data from different years and sources, all variables are normalized by regional GDP.[7]

[5]The table of Haddad et al. (2025) distinguishes 68 economic activities, following the classification adopted in Brazil's Supply and Use Tables. We aggregate the sectors "S41. Trade and repair of motor vehicles and motorcycles" and "S42. Wholesale and retail trade, except motor vehicles", obtaining 67 sectors, as in the Brazilian input-output tables published by IBGE. This aggregation is required to ensure compatibility with the 2019 Brazilian input-output tables of Alves-Passoni and Freitas (2023), which are used to construct the regional capital flows table.

[6]The description of priority activities in Decree No. 4,213/2002 is concise. After establishing an initial correspondence with the 67 sectors of the input-output table, we consulted SUDENE to verify possible discrepancies with the activities effectively supported by the agency.

[7]Specifically, we compute $\eta = 1 - (E_{2022}/GDP_{2022}^{NE})/(G_{2019}/GDP_{2019}^{NE} + S_{2023}/GDP_{2023}^{NE})$. where GDP_t^{NE} gross domestic product of Brazil's Northeast region in year t.

Figure 1: Distortion centrality, Brazil's Northeast region, 2019.



Note: The vertical bars report the distortion centrality values for the 67 sectors, whose labels are listed in Appendix B. Highlighted bars indicate sectors that include activities covered by SUDENE tax incentives.

In our application, all sectors have distortion centrality above $\eta = 0.62$, implying that extending SUDENE tax incentives to all sectors of the Northeastern economy would increase regional income. From the perspective of a Rawlsian planner concerned with raising consumption in a region whose level of development remains below the national average, extending support to a broader set of sectors is therefore justified.

Next, we compute the impact of SUDENE tax incentives on regional income according to Proposition 3. This requires the values of λ and the sectoral subsidy vector. We compute $\lambda = 0.85$ using the variant $\lambda = \left(1 + (1-\eta)\bar{\delta}G/Y^G\right)^{-1}$ of Eq. (14).

The sectoral subsidy vector s_i is obtained from the allocation of SUDENE tax expenditures for 2023, estimated at approximately R$12 billion by the Brazilian Federal Revenue Service (RFB, 2026). This amount is reported in three categories: R$2,565 million for agriculture, R$3.4 million for science and technology, and R$9,430 million for industry. To match the 67-sector classification, the first category is entirely allocated to Sector 1, corresponding to agriculture. The second category, which refers to tax incentives for a digital inclusion project, is allocated to Sectors 31 and 32, which include the manufacture of machinery and equipment. The third category is distributed across all sectors identified as priority sectors under SUDENE, excluding agriculture. In this case, the allocation is proportional to sectoral gross output.

Table 2 reports the estimated impact of SUDENE tax incentives on regional income in 2023.

As shown in the second column of Table 2, the R$12 billion in tax expenditures generates an additional R$6.14 billion in regional income, corresponding to a 0.4% increase. Every R$100 of tax incentives generates R$51 in additional regional income.

The third column of Table 2 reports the results for a counterfactual scenario. We compute the impact of tax incentives under an alternative assignment of subsidies across sectors, in which

Table 2: Impact of SUDENE tax expenditures on regional income, 2023.

	Northeast 2023	**Counterfactual**
As % of regional income	0.40%	0.72%
In R$ billions	6.14	11.2
Per $100 of tax incentives	$51.0	$93.5

Note: Monetary values reported in the second row are expressed in billions of Brazilian reais. Total tax expenditures amount to R$12 billion in 2023.

the vector of sectoral subsidy amounts is held fixed, while the assignment of subsidy amounts to sectors follows the priority ranking recommended by the theory. Under this scenario, the gains are larger, with regional income increasing by 0.72%, equivalent to R$93.5 of additional regional income for every R$100 of tax incentives.

4 Conclusion

In this paper, we extend the production network model of industrial policy developed by Liu (2019) to the case in which government expenditures and sector-targeted subsidies are partially financed by resources from outside the region. We show that this leads to recommending the promotion of a broader set of sectors than would be optimal if all subsidies were financed solely by local taxation.

We then apply the model to analyze SUDENE tax incentives for the development of Brazil's Northeast region. We find that regional income increases by 0.4% and that this effect could be further enhanced either by extending the policy to additional sectors or, while keeping the current level of tax expenditures unchanged, by reallocating subsidies toward sectors with higher priority rankings.

It should be noted, however, that these results are obtained under the assumption that the Northeast is a closed economy. Because trade with the rest of Brazil accounts for a substantial share of the region's economic activity, incorporating interregional trade may alter both the sectoral priority ranking and the estimated policy impacts. Natural extensions of this study would therefore be an open-economy version that incorporates trade with other regions and an adaptation of the framework to incorporate the effects of capital accumulation.

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A Proofs

A.1 Proof of Proposition 1

Proof. From the identity $Y = WL + (1-\eta)G - \eta S$, given in Eq. (12), differentiating $\ln Y$ with respect to τ_{ij} while holding G constant, so that the term $(1-\eta)dG$ vanishes, yields

$$\frac{d\ln Y}{d\tau_{ij}} = \frac{1}{Y}\frac{dY}{d\tau_{ij}} = \frac{1}{Y}\left(\frac{d(WL)}{d\tau_{ij}} - \eta\frac{dS}{d\tau_{ij}}\right). \tag{A.1}$$

For the first term in Eq. (A.1),

$$\frac{d(WL)}{d\tau_{ij}} = WL\frac{d\ln WL}{d\tau_{ij}} = WL\,\mu_j(\omega_{ij}^M + \omega_{ij}^X). \tag{A.2}$$

The last equality follows from Result (I) in Proposition 4 of Martinez and Orrillo (2026), which also applies to the model developed in this paper.

Differentiating S in Eq. (9) with respect to τ_{ij} gives

$$\frac{dS}{d\tau_{ij}}\frac{dS}{d\tau_{ij}} = P_i(M_{ij}+X_{ij}) + \sum_{k=1}^{N}\sum_{n=1}^{N}\tau_{kn}\frac{d[P_k(M_{kn}+X_{kn})]}{d\tau_{ij}}.$$

where the first term represents the direct effect on the subsidized input, while the second captures the indirect effects arising from endogenous changes in the production network. Under the no-intervention benchmark, $\tau = \mathbf{0}$, these indirect effects vanish. Therefore,

$$\left.\frac{dS}{d\tau_{ij}}\right|_{\tau=\mathbf{0}} = P_i(M_{ij}+X_{ij}) = WL\,\gamma_j(\omega_{ij}^M + \omega_{ij}^X), \tag{A.3}$$

where the second equality follows from the definitions of ω_{ij}^M, ω_{ij}^X, and γ_j, which imply $P_iM_{ij} = \omega_{ij}^M\gamma_j WL$ and $P_iX_{ij} = \omega_{ij}^X\gamma_j WL$.

Substituting Eqs. (A.2) and (A.3) into Eq. (A.1), and noting that $WL/Y = \lambda$ in the economy without policy interventions, yields Eq. (13).

□

A.2 Proof of Proposition 2

Proof. Differentiating the consumer budget constraint, $C = WL - T$, with respect to τ_{ij} while holding T constant implies that $dC/d\tau_{ij} = d(WL)/d\tau_{ij}$. Thus, using Eq. (A.2) from the proof of Proposition 1,

$$\left.\frac{dC}{d\tau_{ij}}\right|_{T\text{ fixed}} = WL\,\mu_j(\omega_{ij}^M + \omega_{ij}^X). \tag{A.4}$$

From the government budget constraint in Eq. (10), $G = T/\eta - S$. Differentiating with respect to τ_{ij} while holding T constant gives

$$\left.\frac{dG}{d\tau_{ij}}\right|_{T \text{ fixed}} = -\frac{dS}{d\tau_{ij}}. \tag{A.5}$$

Combining Eqs. (A.3), (A.4), and (A.5) yields the social value of subsidies under fixed T, $\xi_j = \mu_j/\gamma_j$, as stated in Eq. (15).

For the case of fixed G, differentiating Eq. (10) with respect to τ_{ij} and using Eq. (A.3) gives

$$\left.\frac{dT}{d\tau_{ij}}\right|_{\tau=\mathbf{0},\, G \text{ fixed}} = \eta\, WL\, \gamma_j(\omega_{ij}^M + \omega_{ij}^X). \tag{A.6}$$

Since $C = Y - G$ from Eq. (7), it follows that $dC/d\tau_{ij} = dY/d\tau_{ij}$ when G is held fixed. Using Eq. (13) for $d\ln Y/d\tau_{ij}$, and converting the logarithmic variation into a level variation through $dY/d\tau_{ij} = Y\, d\ln Y/d\tau_{ij}$, we obtain

$$\left.\frac{dC}{d\tau_{ij}}\right|_{\tau=\mathbf{0},\, G \text{ fixed}} = Y\,\lambda(\omega_{ij}^M + \omega_{ij}^X)(\mu_j - \eta\gamma_j). \tag{A.7}$$

Combining Eqs. (A.6) and (A.7), together with $\lambda = WL/Y$, yields Eq. (16).

□

A.3 Proof of Proposition 3

Proof. For the aggregate effect of a set of subsidies, it follows immediately from Eq. (13) that

$$\sum_{j=1}^{N}\sum_{i=1}^{N}\left.\frac{d\ln Y}{d\tau_{ij}}\right|_{\tau=\mathbf{0}}\tau_{ij} = \lambda\sum_{j=1}^{N}(\mu_j - \eta\gamma_j)\sum_{i=1}^{N}(\omega_{ij}^M + \omega_{ij}^X)\tau_{ij}.$$

Multiplying and dividing the right-hand side by γ_j, and using $\xi_j = \mu_j/\gamma_j$, gives

$$\sum_{j=1}^{N}\sum_{i=1}^{N}\left.\frac{d\ln Y}{d\tau_{ij}}\right|_{\tau=\mathbf{0}}\tau_{ij} = \lambda\sum_{j=1}^{N}(\xi_j - \eta)\sum_{i=1}^{N}\gamma_j(\omega_{ij}^M + \omega_{ij}^X)\tau_{ij}. \tag{A.8}$$

From $s_j = S_j/WL_j$ and Eq. (9), multiplying by $\theta_j^L = WL_j/WL$ gives

$$s_j\theta_j^L = \sum_{i=1}^{N}\tau_{ij}P_i(M_{ij} + X_{ij})/WL.$$

Since $P_i(M_{ij}+X_{ij}) = (\omega_{ij}^M+\omega_{ij}^X)\gamma_j WL$, it follows that $s_j\theta_j^L = \sum_{i=1}^{N}\gamma_j(\omega_{ij}^M+\omega_{ij}^X)\tau_{ij}$. Substituting this expression into Eq. (A.8) yields Eq. (17).

□

B List of Sectors

Table 3: Sectors ranked by distortion centrality, with $\xi > 1$.

Rank	Sector	Description	ξ	SUDENE
1	7	Non-ferrous metal ore mining, including beneficiation	2.159	Yes
2	5	Oil and gas extraction, including support activities	1.938	Yes
3	4	Coal mining and non-metallic mineral mining	1.876	Yes
4	27	Pig iron, ferroalloys, steel, and seamless steel tubes	1.718	Yes
5	28	Non-ferrous metal metallurgy and metal casting	1.704	Yes
6	21	Manufacture of organic and inorganic chemicals, resins and elastomers	1.662	Yes
7	26	Manufacture of non-metallic mineral products	1.636	Yes
8	37	Maintenance, repair, and installation of machinery and equipment	1.578	Yes
9	43	Water transport	1.506	Yes
10	19	Petroleum refining and coke products	1.488	Yes
11	22	Manufacture of agrochemicals, disinfectants, paints, and other chemical products	1.475	Yes
12	40	Construction	1.465	No
13	49	Television, radio, film, and sound recording and publishing activities	1.464	No
14	29	Fabricated metal products (except machinery and equipment)	1.461	Yes
15	55	Architectural and engineering activities, technical testing and analysis, and R&D	1.449	No
16	35	Manufacture of other transport equipment (except motor vehicles)	1.447	Yes
17	32	Manufacture of machinery and mechanical equipment	1.414	Yes
18	25	Manufacture of rubber and plastic products	1.376	Yes
19	6	Iron ore mining, including beneficiation and agglomeration	1.366	Yes
20	57	Rental services (excluding real estate) and intellectual property asset management	1.358	No
21	54	Legal, accounting, consulting, and head office activities	1.347	No
22	34	Manufacture of motor vehicle parts and accessories	1.346	Yes
23	16	Manufacture of wood products	1.329	Yes
24	17	Manufacture of pulp, paper, and paper products	1.290	Yes
25	51	Software development and other information services	1.283	Yes
26	56	Other professional, scientific, and technical activities	1.273	No
27	31	Manufacture of electrical equipment	1.257	Yes
28	38	Electricity, natural gas, and other utilities	1.237	Yes
29	18	Printing and reproduction of recorded media	1.232	No
30	45	Storage, support activities for transportation, and postal services	1.215	Yes
31	59	Security and investigation activities	1.196	No
32	42	Land transport	1.196	Yes
33	20	Manufacture of biofuels	1.155	Yes
34	58	Other administrative and support services	1.104	No
35	44	Air transport	1.092	Yes
36	9	Sugar manufacturing and refining	1.086	Yes
37	46	Accommodation	1.082	Yes
38	30	Manufacture of computer, electronic, and optical products	1.061	Yes
39	39	Water supply, sewerage, and waste management	1.060	Yes
40	1	Agriculture, including support activities and post-harvest activities	1.059	Yes
41	13	Manufacture of textiles	1.054	Yes
42	33	Manufacture of automobiles, trucks, and buses (except parts)	1.053	Yes
43	41	Wholesale and retail trade	1.052	No
44	2	Livestock, including support activities	1.047	No
45	52	Financial intermediation, insurance, and supplementary pensions	1.005	No

Note: Sectors are ranked in descending order of distortion centrality (ξ). The SUDENE column identifies sectors containing activities eligible for SUDENE tax incentives.

Table 4: Sectors ranked by distortion centrality, with $\xi < 1$.

Rank	Sector	Description	ξ	SUDENE
46	3	Forestry, fishing, and aquaculture	0.994	Yes
47	48	Publishing and integrated printing activities	0.955	No
48	36	Manufacture of furniture and miscellaneous manufacturing products	0.950	Yes
49	24	Manufacture of pharmaceutical products	0.941	Yes
50	50	Telecommunications	0.921	Yes
51	11	Manufacture of beverages	0.913	Yes
52	23	Manufacture of cleaning, cosmetic, and personal care products	0.903	Yes
53	10	Other food products	0.885	Yes
54	15	Manufacture of footwear and leather products	0.841	Yes
55	66	Membership organizations and other personal services	0.837	No
56	65	Arts, creative, and entertainment activities	0.836	No
57	8	Slaughtering and meat products, including dairy and fish products	0.829	Yes
58	53	Real estate activities	0.828	No
59	62	Private education	0.820	No
60	47	Food services	0.814	No
61	12	Manufacture of tobacco products	0.809	No
62	14	Manufacture of wearing apparel and accessories	0.809	Yes
63	64	Private healthcare	0.796	No
64	60	Public administration, defense, and social security	0.788	No
65	61	Public education	0.773	No
66	63	Public healthcare	0.773	No
67	67	Domestic services	0.772	No

Note: Sectors are ranked in descending order of distortion centrality (ξ). The SUDENE column identifies sectors containing activities eligible for SUDENE tax incentives.