Received: 14 May 2020 | Revised: 10 August 2020 | Accepted: 23 August 2020

DOI: 10.1111/rsp3.12337

ORIGINAL ARTICLE

Employment effects of COVID-19 across Chilean regions: An application of the translog cost function

Félix Modrego[1] | Andrea Canales[1,2] | Héctor Bahamonde[1]

[1]Institute of Social Sciences, Universidad de O'Higgins, Rancagua, Chile

[2]Instituto de Economía, Pontificia Universidad Católica de Chile, Santiago, Chile

Correspondence
Félix Modrego, Institute of Social Sciences, Universidad de O'Higgins, Libertador Bernardo O'Higgins 611, Rancagua 2820000, Chile.
Email: felix.modrego@uoh.cl

Funding information
Chilean National Agency of Research and Development (ANID); Institute for Research in Market Imperfections and Public Policy, Grant/Award Number: MIPP, ICM IS130002; FONDECYT Postdoctoral, Grant/Award Number: 3200650; FONDECYT Initiation in Research Fund 2019, Grant/Award Number: 11190112

Abstract

Estimating an aggregated translog cost function for the period 2013–2018, and using alternative scenarios of product loss based on expert projections, this article provides a preliminary forecast of the regional employment effects of COVID-19 across Chilean regions. The total estimated loss in the average scenario was around 705,000 jobs (577,000 in the optimistic and 870,000 in the pessimistic scenarios). Relative impacts were spatially heterogeneous, ranging from 1.5% (Antofagasta Region) to 13.6% (Los Lagos Region) of total regional jobs in the average scenario. Estimated impacts may inform regionally-targeted social protection and economic stimulus policies at a time in which the virus has not fully spread and total regional employment impacts have not been realized. In any region and scenario, estimated losses were sizeable and call for rapid and spread implementation of job and production protection initiatives recently passed as well as others still being discussed in congress.

KEYWORDS

Chile, COVID-19, forecasting, regional employment, translog cost function

JEL CLASSIFICATION

I15; J23; R11

1 | INTRODUCTION

COVID-19 is considered the greatest threat to world health since the Spanish Flu of 1918,[1] and the economic impacts are expected to be comparable in magnitude only to those of the 1929 Great Depression (IMF, 2020). Strict policies have been implemented by most governments to contain the spread of the disease during what has been called the "Great Lockdown" (IMF, 2020). As a result, around half of the world population is currently under confinement.[2] Restrictions to production, consumption and trade start striking harshly the global and national economies. For instance, the US Federal reserve reported a 4.8% reduction in the GDP in the first quarter of 2020. China's GDP, shrank by 6.8%, an outcome that has not been seen in 40 years. In addition, Italy and France fell into a technical recession in the first months of 2020. International trade is expected to decrease between 13 to 32% in 2020 (WTO, 2020). Consequently, the global employment impacts of COVID-19 are expected to encompass around 195 million jobs lost (UN News, 2020).

Several studies have reported that economic recessions are usually characterized by high rates of job destruction (Darby, Haltiwanger, & Plant, 1985, 1986; Davis & Haltiwanger, 1990, 1992). However, the COVID-19 crisis is showing some peculiarities in the way that economic impacts unfold, with the risk of turning a transient shock into one with relatively permanent consequences. Guerrieri, Lorenzoni, Straub, and Werning (2020) observed that in the case of the COVID-19 crisis, the demand may overreact to the supply shock, since the shock can be amplified by mechanisms such as firms' closures and job destruction, thus aggravating the recession. In this context, standard fiscal stimuli may be less effective, which warrants the implementation of large-scale social protection policies. Because these market adjustment mechanisms may operate differently (or at least at a different pace) across regions, it is important to gather estimates of regional job losses to inform regional support strategies. However, the economic effects of the pandemic are currently ongoing and still very few estimations of its sub-national economic effects exist. This paper contributes to filling this gap in knowledge by estimating the employment effects of COVID-19 in Chile, an upper middle-income economy in Latin America with large regional inequalities.

From a regional point of view, Chile is an interesting case to estimate the employment effects of COVID-19. Chile is currently organized administratively in 16 regions, 56 provinces and 346 municipalities (*comunas*). Chilean regions are arranged one on top of each other from north to south (Figure 1). In this paper, we consider the 15 regions that existed up to the end of 2018. [3] The population of Chile is highly concentrated in the metropolitan region of Santiago, Chile's primate city (with around 40% of the national population) and the economic and political core of the country. However, Chile's regional labour markets are extremely heterogeneous. Although most jobs across all Chilean regions constitute retail and unsophisticated services, there are significant variations in the relative importance of the different industries, which are directly related to Chile's physical geography. In the sparsely populated regions of the north, for instance, a large percentage of employees work in mining and mining-related services. In the more densely populated regions in the centre and south of the country, in contrast, agriculture and the agri-food industry account for a relatively large share of the labour force (Olfert et al., 2014). The metropolitan region of Santiago is a largely urban economy, oriented to services and with a much more diverse industrial structure. We approached such heterogeneity by following a regional approach to the estimation of unemployment effects of COVID-19.

This estimation is based on fitting an aggregated cost function using data from the Chilean regions for the period of 2013–2018. We used a flexible functional form (translog) fitted using regional data from several official sources. Despite data limitations, the estimation results are largely consistent with theory. Estimated (region-specific)

[1] See https://www.telegraph.co.uk/news/2020/03/06/coronavirus-poses-serious-threat-public-health-since-spanish/

[2] See: https://www.euronews.com/2020/04/02/coronavirus-in-europe-spain-s-death-toll-hits-10-000-after-record-950-new-deaths-in-24-hou

[3] The region of Ñuble was officially established in September 2018. In all calculations, Ñuble was treated as part of the former region of Biobio from which it originates.

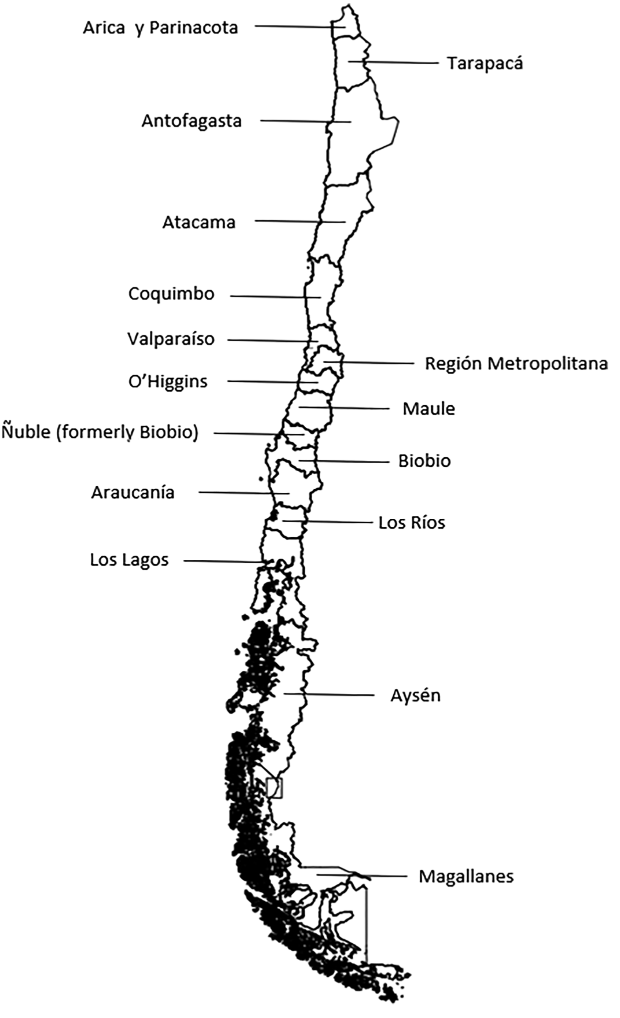

FIGURE 1 Chilean regions

elasticities were used to forecast the impact of Covid-19 on employment across Chilean regions due to product losses, using available expert forecasts to define three scenarios of national product loss. Results indicate a total loss of around 705,000 jobs in the average scenario. In the optimistic scenario, the estimated loss is around 577,000, and 870,000 is estimated in the pessimistic scenario. The approach followed here is based on dual production theory and is similar to the method used by Anríquez and López (2007) to study the employment and wage effects of agricultural expansion in Chile during the 1990s. This approach is grounded on well-established results in microeconomics, and is not particularly data-intensive. However, despite its strengths and applicability, we are unaware of its use for studying the regional employment impacts of COVID-19 (or other public health crises). Thus, this method may provide an econometric alternative to early estimations based on assessments of occupations at risk (Lund, Ellingrud, Hancock, Manyika, & Dua, 2020; Muro, Maxim, & Whiton, 2020).

As expected, the bulk (32%) of predicted job losses was estimated in the metropolitan region of Santiago. However, this is not the region with the largest estimated impacts in relative terms. The results indicated that the relative losses ranged from around 1.5% of regional jobs in the region of Antofagasta (a mining region in the north) to around 13.6% in the region of Los Lagos (a region in the south, mainly oriented to agriculture, aquaculture and the downstream agri-food industry). In any scenario and region, estimated impacts were considerable; therefore, the implementation of determined and widespread policies for the protection of employment and production is well warranted.

The scope of this paper is admittedly limited since it does not provide explanations of the mechanisms by which COVID-19 impacts regional labour markets nor does it compare our forecasts against others obtained using alternative methods. However, this paper contributes to the body of literature on the economic impacts of COVID-19 in several ways. First, it proposes a theory-grounded, regression-based method to account for the employment effects of the disease, a method which is feasible to implement with regional data usually available. Second, it provides statistical inferences at the subnational level, which we think are useful for Chilean regional scientists and national and regional decision makers concerned with the labour impacts of the pandemic. Third, in assessing our estimations, we observed that in the first months of the pandemic in Chile, massive job losses coincided with many workers (many of them informal) becoming inactive. This phenomenon is itself intellectually interesting and politically relevant. While skilled workers are likely to cope better with the pandemic - for instance, by offering their services from home - unskilled workers lack what has been a traditional unemployment-buffering mechanism. This is an important phenomenon to monitor in the different regions of the country. To the best of our knowledge, we are unaware of previous work noting this adjustment in Chilean labour markets in the present COVID-19 context.

The following section presents the method used for estimating the employment effects of COVID-19 in Chilean regions. Section 3 presents the results, and the final section concludes this work.

2 | METHOD

The method for estimating the employment impacts of COVID-19 across Chilean regions is based on dual production theory (Chambers, 1988; Diewert, 1974). We fit a system of equations comprised of an aggregated cost function and the corresponding factor demand equations, using aggregated data from Chilean regions for the period of 2013–2018. Estimated output elasticities were used to calculate job losses in alternative scenarios, which were defined according to expert forecasts of product loss for the Chilean economy due to COVID-19. Product losses were allocated to regions using the initial sectorial impacts in the metropolitan region of Santiago and the regional shares in each sector.

The econometric model uses a translog specification, a flexible functional form which is a second-order approximation of an arbitrary cost function. The properties of the translog cost function have been previously described in the literature (e.g., Berndt, 1991; Christensen, Jorgenson, & Lau, 1971). The use of a flexible functional form has the advantage of, first, acknowledging the substitution relationships among production factors while imposing minimum restrictions to the underlying production technology. Second, it allows for imposing parametric restrictions which are consistent with standard production theory. While the econometric approach proposed here has several advantages, it also has some limitations. The translog cost function is based on a local approximation (i.e. within the neighbourhood of a point) and does not guarantee good "regional" (that is, in a wider region of the factor price space) approximations nor global satisfaction of the regularity conditions (Pollak, Sickles, & Wales, 1984). Moreover, at the cost of flexibility, many parameters must be estimated, which may reduce statistical power when performing inference in small samples like ours (Finch & Finch, 2017). However, we believe this method is functional for the problem at hand, particularly considering the still limited information available on the regional labour impacts of the pandemic.

The starting point is the following translog specification with technological change proposed by Diewert and Wales (1987):

$$lnC(p,y,t) = \alpha_0 + \sum_i \alpha_i lnp_i + \alpha_y lny + \alpha_t (t-t^*) + \left(\frac{1}{2}\right) \sum_i \sum_j \alpha_{ij} lnp_i lnp_j + \sum_i \alpha_{iy} lnp_i lny \quad (1)$$
$$+ \sum_i \alpha_{it} (t-t^*) lnp_i + \alpha_{yt} (t-t^*) lny + \frac{1}{2} a_{tt} (t-t^*)^2,$$

where C is the production cost, i,j index factors, p is the factor's price, y is the output, t is the period and t^* is a reference year, such that $t–t^*$ is a measure of technological change. Homogeneity of degree one in factor prices is imposed through the following parametric restrictions in Equation 1 (Ryan & Wales, 2000):

$$\sum_i \alpha_i = 1; \sum_i \alpha_{iy} = 0; \sum_i \alpha_{it} = 0; \sum_j \alpha_{ij} = 0 \text{ for the } i = 1, \ldots, n \text{ factors}. \tag{2}$$

By Shepard's lemma, one arrives at the conditioned factor demands, as cost shares (s), differentiating 1 with respect to factor prices. For each factor i:

$$s_i(p, y, t) = \alpha_i + \sum_j \alpha_{ij} lnp_j + \alpha_{iy} lny + \alpha_{it}(t - t^*), \quad \forall i. \tag{3}$$

The theoretical restriction of symmetry of the second-order derivatives of the cost function (Young's theorem) is imposed by the following restrictions to the cross-price coefficients in the n factor share equations 3:

$$\alpha_{ij} = \alpha_{ji}, \ \forall i, j. \tag{4}$$

Although Equation 1 contains all the parameters in 3, the system 1–3 (with parametric restrictions 2 and 4) is jointly estimated, in order to increase the statistical efficiency of the estimates (Hussain & Bernard, 2018). Considering the available data, our estimation includes three factors: labour, machinery, and construction. However, of the three share equations in 3, we only estimated the labour and machinery equations, to avoid a singularity problem. System 1–3 is estimated using Zellner's (1962) seemingly unrelated regressions in its iterative version (IT-SUR), which ensures that the arbitrary decision of which equation to exclude carries no consequences in the estimation results (Baum & Linz, 2009).

A check of global concavity of the cost function in each sample point was performed using the approach proposed by Diewert and Wales (1987), and implemented in the Stata software by Baum and Linz (2009). Diewert and Wales (1987) showed that the cost function will be (quasi)concave if the matrix M:

$$M = H - S^k + SS', \tag{5}$$

is negative (semi)definite. This will depend on all the eigenvalues (λ**)** being (non-negative) positive. In 5, H is the Hessian matrix, S is the shares matrix and S^k is a diagonal matrix of shares, all of order $k \times k$, with k being the number of factors in the cost function.

Estimated coefficients of system 1–3 were used to calculate changes in total costs associated with changes in output. Total labour costs (average wages times the number of workers) (C_l) equals:

$$C_l = C * s_l. \tag{6}$$

Taking logarithms in 6 and differentiating both sides with respect to the output, after some manipulations, the change in total labour cost (dCl) in region r as a function of estimated coefficients is:

$$\mathrm{d}C_{lr} = C_{lr} * dlny_r \left(\sigma_{Cyr} + \sigma_{sly}/s_{lr} \right), \tag{7}$$

where $\sigma_{Cyr} \equiv \left(\frac{dlnC}{dlny}\right)_r$ is the output elasticity of total costs obtained from the estimation of 1, and $\sigma_{sly} \equiv \frac{dsl}{dlny} \equiv a_{ly}$ is the output semi-elasticity of the labour share in total costs. It worth noting that since it is dependent on the values of the covariates, the output elasticity of total cost (σ_{Cyr}) in Equation 9 is specific for each observation, while the output

TABLE 1 The data

Variable in the model	Empirical variable	Source
y (output)	Regional GDP (thousands of millions Ch.$)	Central Bank of Chile
p_l (price of labour)	Average income of employed people in the region as an index (base 100 = metropolitan region in 2013)	National Institute of Statistics, national employment survey (ENE), (Nov.–Jan. moving quarter).
p_k (price of machinery)	Capital goods imports price index (national) (base 100 = 2013)	Central Bank of Chile
p_c (price of constructions)	Deflator of fixed capital consumption in the construction sector (national) (base 100 = 2013)	Central Bank of Chile
C_l (labour costs)	$Cl = p_l$ x number of employed people in the region (thousands of millions Ch.$)	Employed people: National Institute of Statistics, national employment survey (ENE), (Nov-Jan. moving quarter).
C_k (machinery costs)	Fixed capital consumption in machinery and equipment (thousands of millions Ch.$). Allocated to regions using the share of each region in total capital.	Fixed capital consumption in machinery and equipment: Central Bank of Chile. Regional share in total capital estimated by Cerda (2018).
C_c (construction costs)	Fixed capital consumption in construction (housing plus rest of construction) (thousands of millions Ch.$). Allocated to regions using the share of each region in total construction workers each year.	Fixed capital consumption in construction (housing plus rest of construction): Central Bank of Chile. Regional share o in total construction workers each year.: National Institute of Statistics, national employment survey (ENE), (Nov.–Jan. moving quarter).
C (total cost)	$C_l + C_k + C_c$	
s_i	Share of factor i in total cost: $s_i = C_i/C$	

elasticity of the labour share (σ_{sly}) is constant across the entire sample space. From Equation 7, it is clear that the change in labour triggered by a change in output includes the effect of output changes on total regional cost (σ_{Cyr}) and factor substitution effects due to changes in the production scale (σ_{sly}).

Changes in total labour costs due to changes in output are then converted into changes in jobs (dl) using the average incomes of workers in each region (p_{lr}):

$$dl_r = \frac{dC_{lr}}{p_{lr}}. \tag{8}$$

The system 1–3 is fitted using annual data from the 15 Chilean regions existing up to 2018 and for the period 2013–2018. Regional GDP as chained volume (based on the 2013 Chilean input–output matrix) in thousands of millions Ch.$ (variable y) is reported by the national accounts system managed by the Chilean Central Bank. Fixed capital consumption in machinery (in thousands of millions Ch.$) is used as a proxy of machinery costs (C_k) and was retrieved from the same source. The fixed capital consumption in machinery was allocated to regions using regional shares in total capital calculated by Cerda (2018). We used the price index of capital goods imports (base 2013 = 100) as a proxy of the price of machinery (p_k). This price index is also reported by the Chilean Central Bank. This variable does not have regional variation, which can introduce some measurement errors. However, as argued by Anríquez and López (2007), the mobility of capital goods across regions is subject to few frictions due to a well-integrated capital market in Chile; thus, the price of capital should not have major regional differences. Fixed capital consumption in construction (housing

TABLE 2 Expert forecasts of product growth for the Chilean economy in 2020

Source	Forecast end of 2019 (% of GDP) (1)	Forecast in June 2020 (% of GDP) (2)	Impact of COVID-19 (% of GDP) (1)–(2)
World Bank	2.5	−4.3	−6.8
OECD	2.4	−5.6	−8
OECD 2/1	2.4	−7.1	−9.5
ECLAC	1	−5.3	−6.3
Average			−7.7

Note: /1 OECD refers to the forecast with only one virus outbreak and OECD2 with a second.

plus the rest of construction, in thousands of millions of Ch.$) was used as the construction costs variable (C_c),and was also taken from the national accounts system. The capital consumption in construction was allocated to regions using the share of each region in total construction workers each year, with the share calculated using the National Employment Survey (ENE, mobile quarter November–January) run by the Chilean National Institute of Statistics (INE). For the price of construction (p_c), we used the deflator of fixed capital consumption in the construction sector in the national accounts system (base 100 = 2013), also unavailable for regions. This is another source of measurement error, which is possibly more important due to, for instance, regional differences in land prices. These are differences that we cannot control with the data at hand. The average income of workers in each region each year was obtained from the INE's Supplementary Survey of Incomes (ESI), an extra module of the ENE survey added each year in the mobile quarter October–December. The workers' average income was multiplied by the regional number of workers to calculate the regional labour costs (C_l) each year. The workers' mean income was turned into an index (base 100 = the metropolitan region of Santiago in 2013) to use in the regressions as the labour price variable (p_l). Total regional costs were obtained adding labour, machinery and construction costs; subsequently, the share of each factor (s_{lr}, s_{kr}, s_{cr}) was computed. A summary of the variables used in the econometric estimation can be found in Table 1.[4]

We defined three scenarios of product loss following the most recent expert forecasts for the Chilean economy (World Bank, OECD and United Nations' ECLAC). The product impact of COVID-19 was defined as the difference between the national product change forecasted before the outbreak of the virus (December 2019–January 2020) and after the outbreak (first days of June 2020). The *average* scenario was defined as an impact equal to the average of the four forecasts and amounts to 7.7%. The *pessimistic* scenario was defined according to the largest impact, the OECD forecast with a second COVID-19 outbreak, which amounts to a 9.5% reduction. The *optimistic* scenario corresponds to the mildest product impact, by UN's ECLAC, which indicates a shrinkage of around 6.3%. The scenarios and the simulation parameters are summarized in Table 2.

Using the expert forecasts, the forecasted product impact in each scenario was allocated to regions using regional weights ($\omega_{r,}$ w_r), such that Equation 8 now reads as:

$$dl_r = C_{lr}/p_{lr} * dy * \omega_r/(y * w_r)\left(\sigma_{Cyr} + \sigma_{sly}/s_{lr}\right), \tag{9}$$

where y is the national product in 2019 and dy is the national product loss (in levels) for 2020 in each scenario. ω_r is a regional parameter used for allocating the forecasted national product loss in 2020 among the (former) fifteen regions, and w_r is the regional share in total product (in 2018, last year available).[5]

The ω_r parameter was calculated as:

[4]Data complied by the Chilean Central Bank was retrieved from its statistics website: https://www.bcentral.cl/areas/estadisticas. Data reported by INE was obtained from INE.stat (https://stat.ine.cl/) and INE databank (http://bancodatosene.ine.cl/) websites.

[5]Total here means the sum of the 15 regions, which is not equal to the national product, as the national GDP includes items which are not suitable for regional allocation.

TABLE 3 System (1)–(3) estimation results

Variable	C	sl	sk
lnpl	0.940*** (0.098)	−0.065*** (0.017)	0.015 (0.020)
lnpl*lnpl	−0.065*** (0.017)		
lnpk	0.060 (0.098)	0.015 (0.020)	−0.000*** (0.000)
lnpk*lnpk	−0.000*** (0.000)		
lnpc	0.000*** (0.000)	−0.052** (0.024)	−0.000 (0.000)
lnpc*lnpc	0.056*** (0.020)	−0.006 (0.026)	0.000*** (0.000)
lny	0.489** (0.202)	−0.001 (0.005)	0.005 (0.006)
lny*lny	0.020* (0.011)		
lnpl*lnpk	0.015 (0.020)		
lnpl*lnpc	−0.006 (0.026)		
lnpl*lny	−0.001 (0.005)		
lnpk*lnpc	−0.000 (0.000)		
lnpk*lny	0.005 (0.006)		
lnpc*lny	−0.005 (0.005)		
t–t*	0.110 (0.108)	0.000** (0.000)	0.000*** (0.000)
(t–t*)2	−0.013** (0.006)		
lnpl*(t–t*)	0.000*** (0.000)		
lnpk*(t–t*)	0.000*** (0.000)		
lnpc*(t–t*)	0.000*** (0.000)		
lny*(t–t*)	0.009 (0.010)		
Constant	−2.889*** (0.985)	0.940*** (0.098)	0.060 (0.098)
Observations	88	88	88
chi2 p-value	0.0000	0.0000	0.4725
Breusch–Pagan test of errors independence (p-value)	0.0000		

Note: significant at *10%, **5%, ***1%. Standard errors in parenthesis.

$$\omega_r = \sum_s w_s^{RM} * w_{sr}. \tag{10}$$

w_s^{RM} is the contribution of each economic sector (s = 1, …,21) to total employment change observed in the metropolitan region of Santiago between February–April 2020 and February–April 2019 (same quarter to avoid seasonality problems), and w_{sr} is the share of region r in total workers in the s sector. Thus, ω_r considers the likely sectoral differences in the employment effects of the pandemic and the importance of each sector in each regional economy.[6]

The use of employment changes in the metropolitan region to calculate the ω_r parameter is grounded in the following reasons. In the period between the first draft of this paper and the revised version, the National Institute of Statistics released the results of the National Employment Survey (NES) for the moving quarter February–April 2020, which allows for assessing the initial employment effects of the virus outbreak. Currently (the first days of June 2020), the Chilean National Government has opted for a strategy of "dynamic lockdowns," in which specific areas (municipalities or specific areas within a municipality) are locked down and released based on the epidemiologic situation, an assessment which is largely based on the spatial concentration of detected COVID-19 cases. By the end of April 2020, the metropolitan region of Santiago accounted for around 80% of total cases (twice its share in the national population) and was the only Chilean region where a sizeable population went into a prolonged (more than

[6]This way of regionally allocating the impacts of COVID-19 was motivated by the comments of an anonymous reviewer to whom we are very grateful.

TABLE 4 Output elasticities of total costs in 2018 for Chilean regions

Region	σ_{Cyr}	Standard error	P-value	95% Confidence interval	
Arica y Parinacota	0.838	0.057	0.000	0.726	0.950
Tarapacá	0.884	0.046	0.000	0.794	0.973
Antofagasta	0.942	0.050	0.000	0.845	1.039
Atacama	0.882	0.046	0.000	0.792	0.972
Coquimbo	0.892	0.045	0.000	0.804	0.980
Valparaíso	0.934	0.048	0.000	0.840	1.028
Metropolitana	0.991	0.068	0.000	0.858	1.124
O'Higgins	0.911	0.045	0.000	0.823	0.998
Maule	0.899	0.044	0.000	0.812	0.986
Biobio	0.930	0.047	0.000	0.838	1.023
Araucanía	0.889	0.045	0.000	0.801	0.978
Los Ríos	0.861	0.050	0.000	0.762	0.959
Los Lagos	0.896	0.045	0.000	0.809	0.984
Aysén	0.828	0.061	0.000	0.708	0.948
Magallanes	0.854	0.052	0.000	0.752	0.956

a few weeks) lockdown. For instance, a large section of the municipality of Santiago, where the city's main business and public administration district is located, entered into lockdown on 26 March 2020, along with six other municipalities, amounting to around 1.3 million people in lockdown. By the first days of June 2020, the municipality of Santiago had not been released yet; on the contrary, the strategy of dynamic lockdowns had shifted to locking down the entire greater Santiago City (34 municipalities) and some surrounding municipalities. The Santiago metropolitan region is the core and largest region, constituting around 40% of the national population, and has the highest sectoral diversity, with all economic sectors well represented. Thus, the results of the February–April round of the NES survey for the metropolitan region of Santiago provide what is arguably the best snapshot currently available of the sectorial employment effects in Chile in the likely event of the spread of the disease within the entire country and the subsequent implementation of total regional lockdowns.

To estimate the employment effects of COVID-19 in each region, total labour costs (C_{lr}), average regional workers' income (p_{lr}), the output elasticity of total costs (σ_{Cyr}) and the share of labour in total costs (s_{lr}) were all evaluated for each region in 2018, which was the last year with all the data available. Confidence intervals for the impacts calculated with equation 9 were obtained using the delta method.

3 | RESULTS

Table 3 summarizes the estimation results of system 1–3 for a filtered sample of 88 observations.[7] The results are largely consistent with the theory. The total marginal effects indicate that costs are non-decreasing in output and factor prices. Factors shares decrease as their prices increase, and point estimates suggest substitution between

[7]The system 1–3 was initially estimated using the full sample of 90 observations (15 regions × 6 years). Estimated elasticities were used to make retrodictions of employment changes in the 2008–2013 period, using Equations 7 and 8. An analysis of the standardized residuals (i.e., the standardized difference between observed and retrodicted employment changes) revealed two clear outliers where the rule-of-thumb criterion of a standardized residual greater than two (in absolute terms) was exceeded. Such outliers were excluded in the final estimations. We are grateful to an anonymous reviewer for motivating this validation exercise.

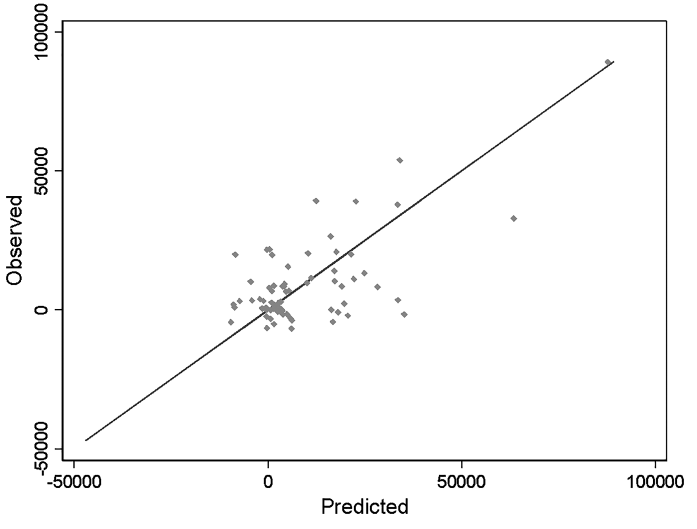

FIGURE 2 Model validation – predicted vs observed regional employment changes for the 2013–2018 period

machinery and constructions. In contrast, there is no clear substitution relationship between labour and the other production factors, although this is probably related to the small sample size and the lack of regional variation of capital and construction prices. Concavity was verified in approximately 76% of the sample. The Breusch–Pagan test confirmed the lack of independence of the errors across equations, which is expected since all derive from the same underlying technology (implicit in the cost minimization problem). Altogether, the results provide confidence in that in spite of considerable data limitations, the estimated translog cost function provides a reasonable representation of the aggregated regional production technology.

Output elasticities of total costs (σ_{Cyr}) in 2018 and their standard errors are reported for each region in Table 4. They range from 0.828 (Aysén, south end of the country) to 0.991 (metropolitan region of Santiago). At a 95% confidence, in 11 out of the 15 regions, total costs responded less than proportionally to changes in output. In particular, the northernmost region (Arica y Parinacota) and the two southernmost (Aysén and Magallanes) are estimated as the less responsive to output changes. The estimated output elasticity of the labour share (constant across the sample space) indicates, however, that the share of labour in total costs is largely invariant to the scale of production (σ_{sly} = −0.0005, not significant). This indicates that the impact of COVID-19 on employment would be mostly due to the reduction in output and would not be substantially buffered (nor amplified) by a substitution of factors triggered by the large product shrinkage. Again, we cannot exclude the possibility that the lack of significance of this second elasticity is due to the lack of regional variation in factor prices and the small sample size. As a simple validation exercise, Figure 2 displays observed against predicted employment changes for the period of 2013–2018. Predictions were obtained using the estimated elasticities in Equations 7 and 8. A 45-degree line was added to ease visualization. A simple regression indicated a R^2 of 0.57 and a slope coefficient of 0.74.[8] Overall, the model seems to capture well the fundamental underlying economic relationships, and the proposed method has been demonstrated to be useful for estimating regional employment effects of COVID-19 in Chile.

Table 5 summarizes the regional parameters used in the calculation of labour impacts with Equation 9, showing the large share (40%) of the Santiago metropolitan region in the national impact (ω_r). The calculated share is, nevertheless, lower than its share in the total product (46%). The region of Antofagasta, the largest mining region in the country, has the lowest calculated share in the national impact (2.4%) relative to its share in the total product (11%). Conversely, Biobio, a region with the third largest urban agglomeration in the country (Concepción), has a high calculated share (12%) in the national impact given its share in the total product (around

[8]The standardized residuals were all below the rule of thumb value of two in absolute terms.

TABLE 5 Regional parameters for the employment impact calculations

Region	Regional GDP 2018 (thousands of millions Ch. $)	Regional weight (ω_r)	Regional share in total product 2018 (w_r)	Total labour costs 2018 (thousands of million Ch.$)	Mean workers annual wage 2018 (thousands Ch.$)	Share of labour in total costs 2018 (%)
Arica y Parinacota	1,111.9	0.009	0.008	436.8	5,819	62.3
Tarapacá	3,433.1	0.016	0.025	1,031.6	6,138	62.8
Antofagasta	14,787.8	0.024	0.106	2,422.4	8,310	59.3
Atacama	3,323.5	0.013	0.024	942.4	6,592	63.4
Coquimbo	4,251.4	0.043	0.030	2,093.7	5,542	67.4
Valparaíso	12,135.3	0.098	0.087	5,584.0	6,589	67.4
Metropolitana	65,031.3	0.404	0.465	27,255.7	8,036	72.5
O'Higgins	6,733.1	0.052	0.048	2,659.4	5,862	70.8
Maule	4,999.9	0.067	0.036	2,692.9	5,287	66.0
Biobio	11,018.5	0.116	0.079	5,361.9	5,550	68.3
Araucanía	3,951.6	0.053	0.028	2,512.0	5,333	64.2
Los Ríos	1,947.4	0.027	0.014	1,122.5	5,868	66.3
Los Lagos	4,706.1	0.060	0.034	2,686.9	6,047	68.9
Aysén	856.1	0.008	0.006	468.3	7,494	67.7
Magallanes	1,654.8	0.010	0.012	890.7	10,134	77.2

Notes: /1 dy = – 11,961.1 (th. MM Ch. $) in the average, (th. MM Ch. $) -14,757.2 in the pessimistic and –9.786.4 (th. MM Ch. $) in the optimistic scenario. σ_{sly}= – 0.0005 for all regions. σ_{Cyr} in Table 4. /2 "Total" costs are the sum of labour, machinery and constructions costs.

TABLE 6 Estimated impacts of COVID-19 on regional employment

Region	Average scenario			Optimistic scenario			Pessimistic scenario		
	Estimate	95% confidence interval		Estimate	95% confidence interval		Estimate	95% confidence interval	
Arica y Parinacota	−5,468	−6,208	−4,727	−4,474	−5,079	−3,868	−6,746	−7,659	−5,832
Tarapacá	−7,535	−8,313	−6,758	−6,165	−6,802	−5,529	−9,297	−10,257	−8,337
Antofagasta	−4,753	−5,255	−4,251	−3,889	−4,299	−3,478	−5,864	−6,483	−5,245
Atacama	−5,303	−5,854	−4,752	−4,339	−4,789	−3,888	−6,542	−7,222	−5,863
Coquimbo	−36,561	−40,213	−32,910	−29,914	−32,901	−26,926	−45,108	−49,613	−40,603
Valparaíso	−68,895	−75,910	−61,879	−56,368	−62,109	−50,628	−85,000	−93,656	−76,344
Metropolitana	−224,874	−255,276	−194,471	−183,987	−208,862	−159,113	−277,441	−314,951	−239,932
O'Higgins	−34,320	−37,663	−30,976	−28,080	−30,816	−25,344	−42,343	−46,468	−38,217
Maule	−65,848	−72,327	−59,369	−53,876	−59,176	−48,575	−81,241	−89,234	−73,248
Biobio	−102,136	−112,385	−91,887	−83,566	−91,951	−75,180	−126,012	−138,656	−113,367
Araucanía	−59,980	−66,027	−53,934	−49,075	−54,022	−44,128	−74,002	−81,462	−66,542
Los Ríos	−24,500	−27,340	−21,659	−20,045	−22,369	−17,721	−30,227	−33,731	−26,723
Los Lagos	−54,964	−60,405	−49,523	−44,970	−49,422	−40,519	−67,812	−74,525	−61,100
Aysén	−5,279	−6,052	−4,506	−4,319	−4,952	−3,687	−6,513	−7,467	−5,559
Magallanes	−5,013	−5,623	−4,403	−4,102	−4,601	−3,603	−6,185	−6,937	−5,433
Total	−705,428			−577,168			−870,333		

8%). This is due to the specific regional employment structure, which is characterized by a relatively large weight of agriculture and manufacturing, two sectors showing large initial employment impacts. According to the February–April ENE survey, retail, lodging and restaurants and manufacturing are the sectors that have been most affected initially by the COVID-19 shock, while others sectors such as health, education or mining are far less. While high-risk sectors such as lodging and restaurants correspond to the sectors at the greatest risk in the US (Muro et al., 2020), others like mining (described as a high-risk sector in the US) are not among the industries with the highest initial job losses according to the ENE survey. This finding suggests some particularities of the sectorial employment effects of COVID-19 in Chile.

Table 6 summarizes the estimated employment losses in each region and their 95% confidence intervals and Figure 3 maps these losses as a percentage of total regional jobs. Overall, total job losses were more or less proportional to the expert forecasts of product shrinkage, since regional output elasticities were close to unity and the estimated output elasticity of the labour share in total costs was negligible. Total job losses amounted to around 705,000 in the average scenario. In the pessimistic scenario, job losses amount to nearly 870,000 and to 577,000 in the optimistic scenario. Examining the regional variation of impacts, almost a third of the national variation (nearly 225,000 jobs) was estimated in the metropolitan region of Santiago, although this figure was considerably less than its share in national employment (44%). The least impacted region in relative terms would be the region of Antofagasta, a region where mining accounts to around 54% of the regional GDP. In the average scenario, job

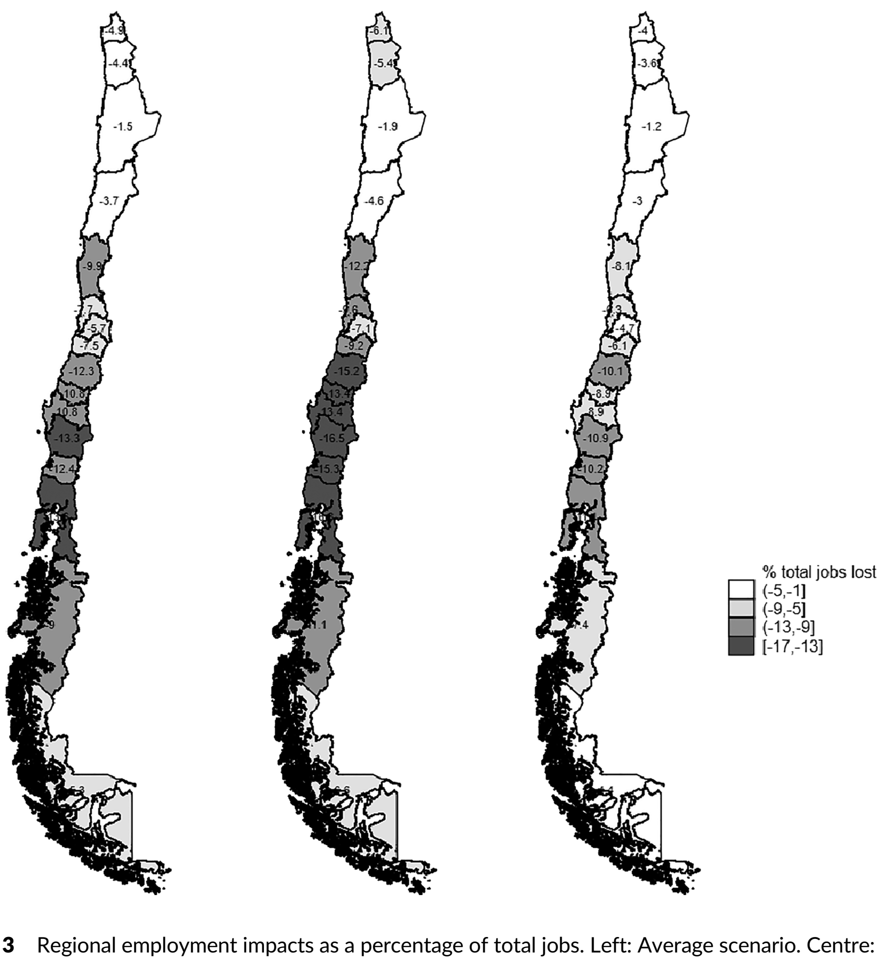

FIGURE 3 Regional employment impacts as a percentage of total jobs. Left: Average scenario. Centre: Pessimistic scenario. Right: Optimistic scenario

losses would be of around 4.800, which means around 0.7% of the national job loss. This is proportionally less than its share in the national employment (3.6%), and only a 1.5% of total regional jobs. While the expenditures in production factors have been relatively sensitive to output variations (Table 4) in Antofagasta compared to other regions, the regional employment structure is highly specialized in mining, a sector that has not been one of the most affected by the disease based on the evidence so far. Antofagasta's economy is highly sensitive to the copper price cycle (Atienza & Modrego, 2019), and the slow recovery in copper-buying countries (mainly China) will likely help mitigatethe employment effects of the pandemic. In contrast, the region of Los Lagos is the most affected region in relative terms (13.6% of total regional employment in the average scenario, Figure 3). Los Lagos is a region located in the south of the country, oriented to the production of primary natural resources and its downstream agri-food industry. Agriculture, livestock, forestry, fishing and aquaculture alone account for around 12% of the regional product and manufacturing adds another 26%. Although the region's factors expenditure had an approximately average sensitivity to output changes (Table 4), its specialization in agriculture and (agri-food) manufacturing (two of the sectors most initially affected by COVID-19) has resulted in the large forecasted employment impacts in relative terms. More generally, Figure 3 illustrates how mining regions in the north of the country (Tarapacá, Antofagasta and Atacama) are predicted to have lower relative job losses compared to agriculture and agri-food-oriented regions in the centre and centre–south (Maule, Araucanía, Los Ríos and Los Lagos).

Overall, in all regions and scenarios, the estimated regional employment effects of COVID-19 are sizeable and call for determined actions to the protect employment and production within the entire country. Since the pandemic is currently ongoing, and forecasts of economic impacts for the Chilean economy may still change, these estimations should be considered to be a preliminary approximation.

4 | CONCLUSIONS

This paper presents preliminary forecasts of employment losses in Chile at the regional level resulting from the COVID-19 pandemic. Following a methodological approach based on the estimation of an aggregated cost function for the period of 2013–2018 and on dual production theory, the employment losses were calculated for different scenarios of national product loss. The estimations suggest sizeable impacts. In the average scenario, the estimated impact was around 705,000 jobs country-wide, which amounts to 870,000 and 577,000 in the pessimistic and optimistic scenarios, respectively. In regional terms, impacts are heterogeneous across regions, with agriculture and agri-food oriented regions in the centre–south more affected than mining regions in the north.

These estimates are preliminary, and should be taken with caution. A first limitation of this study is based on the data, particularly the lack of regional data on consumption and prices of several production factors. Producing better estimates would be possible with more complete regional data, particularly data on consumption and prices of production factors. A second limitation is that we did not explicitly model the spatial spread of the disease nor the output impacts of COVID-19 in each region. Instead, we relied on expert forecasts for the national economy, which are regionally allocated in a more or less *ad-hoc* way, and implicitly assuming a uniform spread of the virus throughout the country. Finally, statistical relationships were estimated using data for a period of moderate growth of the national economy. However, estimated elasticities were used to forecast job losses in a situation of product loss not seeing during the period for which such elasticities were estimated. It is unclear whether employment adjustments in the COVID-19 context will be directly proportional to those seen in the 2013-2018 period. Indeed, the results of the ENE survey for the moving quarter February–April 2020 suggest that adjustment mechanisms that have not been previously observed, at least in the last decades, are currently taking place in the Chilean labour market. Traditionally, self-employment and informality have been powerful buffer mechanisms containing unemployment outbreaks during previous crises. During the COVID-19 crisis, an unusual rise in the number of inactive people (around 720 thousand people) has accompanied an increase in unemployment of only 0.9 percentage points between January–March and February–April 2020. At the same time, there was a large reduction in informal jobs (around 415,000). Both these observations suggest that many jobs lost are due to informal and self-employed workers exiting the labour market, a pattern not observed at such a large scale during the 2013–2018 period. This phenomenon is important itself and deserves further research and monitoring by national and regional authorities.

Based on these considerations, total job losses at the end of 2020 may exceed the present forecasts. Indeed, between the last two moving quarters, a period capturing only the initial employment effects of COVID-19, the National Employment Survey (ENE) reported a fall of around 706 thousand in the number of employed individuals already, very close to what we forecasted for the average scenario. The inactive people and the unemployed people behind these figures may amplify the recession in the sense of Guerrieri et al. (2020). If that is the case, the expert forecasts of product losses we are using may also fall short, as the downwards corrections in most expert projections between April and June suggest.

Keeping these caveats in mind, the extent of estimated impacts is large (around 700 to 870,000 jobs potentially lost), calling for resoluted actions to protect employment and production in the entire country. As a response to the virus outbreak, sizeable support packages have been implemented in Chile and others are currently being discussed. Actions already implemented include modifications to the national employment insurance to be used in situations of temporary job suspensions (thus avoiding firings), insurance supported by supplementary public funds, state-guaranteed loans with near-zero real interest rates for firms and additional cash and in-kind transfers to vulnerable households. Regarding the reformed unemployment insurance, the last ENE survey indicated an increase of around 365,000 “absent employees” (people with a job that was nevertheless not performed on-site last week), a change of a magnitude which is partly explained by the reformed employment insurance.

Regional authorities should be prepared for a rapid and effective implementation of these support initiatives, maintaining close monitoring of their communities and collaborating in targeting and implementing national support initiatives. Employers can also contribute to this effort by making a correct use of the employment protection insurance, limiting its use to cases when it is truly needed, and rapidly processing the requests to activate the insurance. Financial institutions can also play an important role in helping mitigate the economic consequences of COVID-19, by rapidly and effectively issuing state-guaranteed loans to firms that need them the most, particularly the small and medium-sized firms.

A direct extension of this work is the replication of the analysis for regional industries, which can be carried out to assess the sectoral impacts in each region, thus informing regional protection and recovery strategies. Likewise, a better understanding of the different types of contractual arrangements that are predominant in each productive sector as well as the sensitivity of jobs to economic shocks under these different contractual arrangements, can shed light on more specific employment protection policies for this crisis and other future crises. Finally, this work has not taken into consideration regional interactions which could significantly alter the estimated regional distribution of the impacts of COVID-19. These interactions may stem, for instance, from physical and human capital externalities and regional growth spillover effects (Valdez, 2019), and could be analyzed using spatial econometric methods, inter-regional input–output analysis and/or regional computable general equilibrium models. Global VAR (GVAR) models (Pesaran, Schuermann, & Weiner, 2004), which have been applied to forecasts of regional unemployment in Germany (Schanne, Wapler, & Weyh, 2010), are also a particularly appealing alternative for forecasting and simulating regional impacts of COVID-19. Further studies along these lines can substantially expand our understanding of the mechanisms by which the effects of the pandemic may diffuse across regions.

ACKNOWLEDGEMENTS

The authors are grateful to the two anonymous reviewers for their very helpful comments and suggestions. Any errors are solely the authors' responsibility. Modrego wishes to thank the support of the Chilean National Agency of Research and Development (ANID) through the FONDECYT Initiation in Research Fund 2019 [Grant: 11190112].

Canales is partially supported by FONDECYT Postdoctoral Grant No. 3200650 and by the Institute for Research in Market Imperfections and Public Policy, MIPP, ICM IS130002.

ORCID

Félix Modrego https://orcid.org/0000-0002-7428-0039

Andrea Canales https://orcid.org/0000-0001-7536-0674

Héctor Bahamonde https://orcid.org/0000-0002-1146-6426

REFERENCES

Anríquez, G., & López, R. (2007). Agricultural growth and poverty in an archetypical middle income country: Chile 1987–2003. *Agricultural Economics*, *36*(2), 191–202.

Atienza, M., & Modrego, F. (2019). The spatially asymmetric evolution of mining services suppliers during the expansion and contraction phases of the copper super-cycle in Chile. *Resources Policy*, *61*, 77–87.

Baum, C. F., & Linz, T. (2009). Evaluating concavity for production and cost functions. *The Stata Journal*, *9*(1), 161–165.

Berndt, E. R. (1991). *The practice of econometrics: Classic and contemporary*. Reading, MA: Addison-Wesley Publishing.

Cerda, H. A. (2018). Inversión, stock de capital e infraestructuras en la economía chilena: una aproximación por regiones y actividad económica, 1990–2010. Ph.D. Thesis, Universidad Complutense de Madrid.

Chambers, R. G. (1988). *Applied production analysis: A dual approach*. New York: Cambridge University Press.

Christensen, L. R., Jorgenson, D. W., & Lau, L. J. (1971). Conjugate duality and the transcendental logarithmic production function. *Econometrica*, *39*(4), 255–256.

Darby, M. R., Haltiwanger, J. C., & Plant, M. W. (1985). Unemployment-rate dynamics and persistent unemployment under rational expectations. National Bureau of Economic Research Working Paper 1558.

Darby, M. R., Haltiwanger, J. C., & Plant, M. W. (1986). The ins and outs of unemployment: The ins win. National Bureau of Economic Research Workingh Paper 1997.

Davis, S. J., & Haltiwanger, J. (1990). Gross job creation and destruction: Microeconomic evidence and macroeconomic implications. *NBER Macroeconomics Annual*, *5*, 123–168.

Davis, S. J., & Haltiwanger, J. (1992). Gross job creation, gross job destruction, and employment reallocation. *The Quarterly Journal of Economics*, *107*(3), 819–863.

Diewert, W. E. (1974). Applications of duality theory. In M. D. Intrilligator & D. A. Kendrick (Eds.), *Frontiers of quantitative economics* (Vol. II) (pp. 106–171). Amsterdam: North-Holland Publishing.

Diewert, W. E., & Wales, T. J. (1987). Flexible functional forms and global curvature conditions. *Econometrica*, *55*(1), 43–68.

Finch, W. H., & Finch, M. E. H. (2017). Multivariate regression with small samples: A comparison of estimation methods. *General Linear Model Journal*, *43*, 16–30.

Guerrieri, V., Lorenzoni, G., Straub, L., & Werning, I. (2020). Macroeconomic implications of COVID-19: Can negative supply shocks Ccause demand ahortages?. National Bureau of Economic Research Working Paper 26918.

Hussain, J., & Bernard, J. T. (2018). Flexible functional forms and curvature conditions: Parametric productivity estimation in Canadian and US manufacturing industries. In W. H. Greene, L. Khalaf, P. Makdissi, R. C. Sickles, M. Veall, & M. C. Voia (Eds.), *Productivity and inequality* (pp. 203–228). New York: Springer.

International Monetary Fund (IMF). (2020). World economic outlook, April 2020: The great lockdown. Washington, DC: IMF Retrieved from https://www.imf.org/en/Publications/WEO

Lund, S., Ellingrud, K., Hancock, B., Manyika, J., & Dua, A. (2020). Lives and livelihoods: Assessing the near-term impact of COVID-19 on US workers. McKinsey global institute. Retrieved from https://www.mckinsey.com/~/media/McKinsey/Industries/Public%20Sector/Our%20Insights/Lives%20and%20livelihoods%20Assessing%20the%20near%20term%20impact%20of%20COVID%2019%20on%20US%20workers/Lives-and-livelihoods-Assessing-the-near-term-impact-of-COVID-19-on-US-workers.pdf

Muro, M., Maxim, R., & Whiton, J. (2020). The places a COVID-19 recession will likely hit hardest. The Brookings Institution. Metropolitan Policy Program. Retrieved from https://www.brookings.edu/blog/the-avenue/2020/03/17/the-places-a-covid-19-recession-will-likely-hit-hardest/

Olfert, M. R., Partridge, M., Berdegue, J., Escobal, J., Jara, B., & Modrego, F. (2014). Places for place-based policy. *Development and Policy Review*, *32*(1), 5–32.

Pesaran, M. H., Schuermann, T., & Weiner, S. M. (2004). Modelling regional interdependencies using a global error-correcting macroeconometric model. *Journal of Business and Economic Statistics*, *22*, 129–162.

Pollak, R. A., Sickles, R. C., & Wales, T. J. (1984). The CES-translog: Specification and estimation of a new cost function. *The Review of Economics and Statistics*, *66*(4), 602–607.

Ryan, D. L., & Wales, T. J. (2000). Imposing local concavity in the translog and generalized Leontief cost functions. *Economics Letters*, *67*(3), 253–260.
Schanne, N., Wapler, R., & Weyh, A. (2010). Regional unemployment forecasts with spatial interdependencies. *International Journal of Forecasting*, *26*(4), 908–926.
UN News. (2020). COVID-19: impact could cause equivalent of 195 million job losses, says ILO chief. Media release. Retrieved from https://news.un.org/en/story/2020/04/1061322
Valdez, R. I. (2019). Spatial diffusion of economic growth and externalities in Mexico. *Investigaciones Regionales—Journal of Regional Research*, *45*, 139–160.
World Trade Organization (WTO). (2020). Trade set to plunge as COVID-19 pandemic upends global economy. World Trade Organization Press Release 855. Retrieved from https://www.wto.org/english/news_e/pres20_e/pr855_e.htm
Zellner, A. (1962). An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias. *Journal of the American Statistical Association*, *57*(298), 348–368.

How to cite this article: Modrego F, Canales A, Bahamonde H. Employment effects of COVID-19 across Chilean regions: An application of the translog cost function. *Reg Sci Policy Pract*. 2020;1–17. https://doi.org/10.1111/rsp3.12337