Resource effect in the Core–Periphery model

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ABSTRACT
This paper develops an extension of Krugman’s Core–Periphery (CP) model by considering a competitive primary sector that extracts a renewable natural resource. The dynamics of the resource give rise to a new dispersion force: the resource effect. If primary goods are not tradable, lower trade costs boost dispersion, and the agglomeration–dispersion transition is sudden or smooth depending on the productivity of the primary sector. Cyclic behaviours arise for high levels of productivity in resource extraction. If primary goods are tradable, in most cases, the symmetric equilibrium goes from stable to unstable as the openness of trade increases.

KEYWORDS
natural resources, New Economic Geography, non-linear dynamics, agglomeration–dispersion forces, bifurcations

JEL F12, F18, Q01, R12

INTRODUCTION
The New Economic Geography (NEG) literature has mainly focused on industrialized economies, overlooking rural or resource-based economies. However, of the 80 million migrants worldwide in 1990, 25 million migrated for environmental reasons or because of resource degradation (Carr, 2009). Many of these migratory movements originated in rural or developing countries. Since the mid-20th century, about 1.2 billion hectares of land around the world have suffered soil degradation, with the consequent declines in yields and harvests, therefore causing massive numbers of environment-induced migrants (Swain, 1996). These migratory processes have important consequences on the spatial distribution of the economic activity, and an analysis of their provoking forces is merited. This is the aim of this paper, which extends the benchmark Core–Periphery (CP) model (Krugman, 1991) by incorporating a (renewable) natural resource.

There are a number of well-documented examples of migration and redistribution of economic activity motivated by the depletion of renewable natural resources. Kirby (2004) describes the geographical movements of fleets and main harbours in the exploitation of oyster fisheries along the coasts in eastern and western North America, and eastern Australia. Andrew et al. (2003) report how, in Chile, the reduction in the biomass and overexploitation of the sea urchin led to the appearance of new fleets, ports and processing facilities in the south, while the harvesting of the
resource tended to diminish in the middle regions of the country. After several years of rapid expansion of the fisheries into the southernmost region, due to the renewing ability of the resource, the proportional contribution to the national harvest of the middle regions began to recover, which boosted the economic activity in the region again. In Madagascar, farmers clear their land with ‘slash and burn’ strategies, which lead to deforestation and soil degradation. They proceed to cultivate the land for a couple of years until the soil is exhausted, after which they move on to new unexploited lands (Jouanjean, Tucker, & te Velde, 2014). Other examples can be found for Brazil, the Dominican Republic, Nicaragua and Costa Rica (Carr, 2009; Chambron, 1999), and Guatemala and Sudan (Bilsborrow & DeLargy, 1990). Anderson, Flemming, Watson, and Lotze (2011) provide an overview of the exploitation of the sea cucumber fisheries where the same behavioural pattern is observed: resource degradation in highly agglomerated regions triggers a process that forces population and economic activity away to new unexploited regions.

The resulting dispersion process depends heavily on the resource: its regenerative ability, the harvesting effort and the techniques used. These elements are not taken into account in NEG models (designed mainly for industrialized economies), where the only dispersion effects arise from the competition among industrial firms and the existence of transport costs. A comprehensive analysis should also take into account the effects of environment and resource degradation.

Transport cost is an important element in the NEG literature and it also plays an important role in the development of rural economies. Reduction in transportation costs and the construction of new roads and infrastructures all facilitate access to distant regions. The profitability of the exploitation of natural resources in far away areas increases, which allows the expansion of the economic activity. For example, a curious land-use dynamics took place in Laos, the Philippines and Amazonia, where landowners intensified their agriculture activities close to new or improved roads. At the same time, forests began to regenerate in regions farther away from the roads (Laurance, Goosem, & Laurance, 2009). Reymondin et al. (2013) study five infrastructure projects for Brazil, Paraguay, Peru, Panama and Bolivia, where these new roads led to forest exploitation, deforestation and expansion of the agricultural frontier to new, unexploited regions. Furthermore, in Brazil, Pfaff (1999) and in Bolivia, Kaimowitz, Méndez, Puntodewo, and Vanclay (2002), highlight that unexploited soil of better quality together with new roads increased the probability of deforestation in order to expand agricultural exploitations for Brazil and Bolivia, respectively.

Therefore, the resulting spatial structure of the economic activity depends on the interaction between transport costs and the resource dynamics. Lower transport costs facilitate trade, which increases the profitability of exploiting distant areas, so encouraging migration and spatial expansion of the economic activity. Additionally, areas whose exploitation has declined, due to the shift in the economic activity, tend to experience a regeneration of their natural resources. Thus, a reduction in transport costs reinforces the dispersion effect driven by the resource dynamics.

Helpman (1998) studies how a fixed endowment (land) boosts the dispersion of the economic activity. Some extensions of this model are found in Suedekum (2006), Pflüger and Südekum (2008), Pflüger and Tabuchi (2010), Leite, Castro, and Correia-da-Silva (2013) and Cerina and Mureddu (2014). These models adjust well for industrialized economies, where congestion and competition for land (a fixed resource) is the driving force of dispersion. Population is the only dynamic factor. However, it does not seem sufficient for regions that base their economic activity on dynamic/renewable natural resources. In resource-based economies the dispersion depends on two fundamental aspects: how the exploitation of the natural resource takes place and how well this resource regenerates itself. Thus, population and resource dynamics interact. An agglomerated equilibrium may be stable if the resource endowment is fixed, while it becomes unstable once the dynamics of the resource is taken into account. The resulting spatial distribution of the economic activity is completely different.

There have been some attempts to incorporate notions from environmental economics into NEG models. Pflüger (2001) studies the option of imposing taxes on emissions; Zeng and
Zhao (2009) and Rauscher (2009) extend some NEG models to study the impact of pollution on the spatial configuration of the economy; Rieber and Tran (2009) investigate the consequences of unilateral environmental regulations; and Rauscher and Barbier (2010) highlight the conflict arising from competition for space between economic and ecological systems. Other attempts to shift the focus from the industrial sector to other sectors of an economy are Lanaspa and Sanz (1999), Berliant and Kung (2009), and Sidorov and Zhelobodko (2013). However, the regenerative ability of natural resources and the extractive efficiency of harvesting efforts is not considered.

To the best of our knowledge, the literature has not incorporated these elements in NEG models. We modify the original CP model by introducing the dynamics of a renewable natural resource, which is extracted as a primary good (Clark, 1990; Vardas & Xepapadeas, 2015), and the double function of primary goods, both as an input for industrial production and as a final consumption good (Pflüger & Tabuchi, 2010). We assume that agents are myopic, that is, they extract the resource without taking into account its dynamics. This set-up is the most consistent with the examples found in the literature.

In our model, industrial goods are produced using the primary good as a raw material and there is free labour mobility between sectors and regions. We study both non-tradable primary goods (fertile land, drinking water or perishable natural goods) and tradable primary goods (agricultural goods). Under the assumptions of non-tradability of the primary good and free labour mobility across sectors, the market size effect dominates the competition effect, as in Helpman (1998). The renewable natural resource and its dynamics are then the main mechanisms that drive dispersion, giving rise to the resource effect. The effect of transport cost on the stability of dispersion and agglomeration is reverted. This is compatible with the pattern described by the empirical literature: lower transport costs and resource degradation encourage migrations process and the distribution of the economic activity.

The extraction productivity of the primary sector determines the strength of the resource effect, determining how the transition from agglomeration to dispersion takes place. When dispersion forces are weak (low extraction productivity) there is an abrupt transition from agglomeration to dispersion, as the cases of the fishery industry pointed out before. When dispersion forces are strong, a smooth transition can take place, such as the reported cases of slow depopulation driven by decline in soil fertility. Moreover, if dispersion forces are strong enough (relative to transport costs), cyclical behaviour may arise: an agglomeration process raises the primary demand, so encouraging larger extractions that compromise the long-term level of the resource and its future extractions. Later, this primary price increases sufficiently to revert the migration process. This is compatible with the chase-and-flee cycle of Rauscher (2009) in the environmental literature, and also with the definitions of circular migration in the migration and economic labour literature (Newland, 2009).

If the primary good is tradable, the openness of trade affects the traditional dispersion–agglomeration forces and also the strength of the new one linked to the resource and its dynamics. Numerical analysis highlights some regularities. First, as the primary good becomes more tradable, the advantage of being in the region with the higher sustainable level of resource is reduced, which weakens the associated dispersion forces. Second, the predominant pattern observed for the symmetric equilibrium is the one that goes from stable to unstable as transport costs decreases.

The paper is organized as follows. The next section introduces the model. The third section studies the case of non-tradable primary goods and in the fourth section the trade of primary goods is allowed. The fifth section concludes.

**THE MODEL**

A world with two regions ($j = 1, 2$) is considered. Two kinds of goods are assumed: manufactures, produced by an increasing-returns sector that can be located in either region, and a primary good
that is extracted or harvested from a resource endowment by competitive firms in each region. The industrial sector uses two inputs to produce manufactures: labour and primary good. The primary sector uses only labour for the extraction of the resource. Hereinafter, the extracted goods from the primary sector will be called primary goods when their destination is to be consumed, and raw materials when their destination is to be used as inputs. Finally, to incorporate the dynamics of the natural resource and its relation with economic activity in a simple way, we assume that there is free labour mobility between industrial and primary sector. This assumption makes the model extremely tractable. Moreover, if there were no mobility at all between sectors, the dynamics of the resource and its long-run stock, as will be shown below, would be independent of changes in economic activity. Then, the model would be similar to Helpman (1998) and Pfüger and Tabuchi (2010).1

Households
Households seek to maximize their utility, which takes the form of a nested Cobb–Douglas (across sectors) and CES (over the varieties) used in the original Krugman model (1991). Thus, a representative household in region 1 solves the following consumption problem:

$$\max_{c_{1i}, c_{2i}, c_{H1}, c_{H2}} U_1 = \ln \left( C_{M1}^{\mu} C_{H1}^{1-\mu} \right)$$

subject to

$$w_1 = \int_0^{n_1} c_{1i} p_{1i} di + \int_0^{n_2} c_{2i} p_{2i} \tau di + p_{H1} c_{H1} + p_{H2} c_{H2} \nu$$

with parameter $\mu \in (0, 1)$ and

$$C_{M1} = \left( \int_0^{n_1} c_{1i} \sigma_{di} di \right)^{\frac{\sigma}{\sigma - 1}}$$

$$C_{H1} = \left( \frac{\sigma - 1}{\epsilon_{H1} + \epsilon_{H2}} \right)^{\frac{\sigma}{\sigma - 1}}$$

where $C_{M1}$ and $C_{H1}$ are consumption indexes of industrial and primary goods respectively with $\sigma > 1$ (for simplicity we assume the same elasticity of substitution for both sectors); $c_{ji}$ is the consumption of variety $i$ produced in region $j$ ($j = 1, 2$); $n_j$ is the number of varieties existing in region $j$; because of free labour mobility, the salary is the same in both sectors and $w_j$ is the income per household in region $j$; $c_{H1}$ and $c_{H2}$ are the consumptions of the primary or harvested good extracted in regions 1 and 2 respectively (Fujita, Krugman, & Venables, 2001, ch. 7); $p_{ji}$ is the price of the variety $i$ of the industrial good produced in region $j$; $\tau > 1$ and $\nu > 1$ are iceberg transport costs of industrial and primary goods, respectively; and finally, $p_{Hj}$ is the price of the primary good of region $j$. The mirror-image problem is solved for households in region 2.

From the first order conditions of the maximization problem (1)–(2), the following demand functions are obtained:

$$c_{1i} = C_{M1} \left( \frac{p_{1i}}{P_1} \right)^{-\sigma}, \quad c_{2i} = C_{M1} \left( \frac{p_{2i} \tau}{P_1} \right)^{-\sigma} \quad \text{with} \quad C_{M1} = \frac{\mu w_1}{P_1}$$

with $\mu \in (0, 1)$ and $\sigma > 1$. The mirror-image problem is solved for households in region 2.


\[ c_{H_1} = C_{H_1} \left( \frac{p_{H_1}}{P_{H_1}} \right)^{-\sigma}, \quad c_{H_2} = C_{H_1} \left( \frac{p_{H_1} \nu}{P_{H_1}} \right)^{-\sigma} \text{ with } C_{H_1} = \frac{(1 - \mu) \omega_1}{P_{H_1}} \]

(6)

where \( P_1 \) and \( P_{H_1} \) are the industrial and primary price indexes for region 1, that is:

\[ P_1 = \left( \int_0^{n_1} p_{1i}^{1-\sigma} di + \int_0^{n_2} (p_{2i} \nu)^{1-\sigma} di \right)^{1-\sigma} \]

(7)

\[ P_{H_1} = \left( p_{H_1}^{1-\sigma} + (p_{H_2} \nu)^{1-\sigma} \right)^{1-\sigma} \]

(8)

Mirror-image formulas for \( P_2 \) and \( P_{H_2} \) hold for consumers in region 2.

**Primary sector**

In the natural extractive sector, a primary firm seeks to maximize its benefits, in a perfect competitive market, choosing the amount of labour to employ in the extraction of the resource, subject to the extraction function for region \( j \), given by:

\[ H_j = \epsilon S_j L_{H_j}, \quad \epsilon > 0 \]

(9)

where \( S_j \) is the available stock of the natural resource; \( L_{H_j} \) is the labour employed in the primary sector; and \( \epsilon \) is a productivity parameter in the extraction, assumed to be equal for both regions for simplicity. As is usual in environmental economic models, the productivity of labour depends positively on the available stock of the natural resource \( S_j \). Firms are myopic, that is, they extract the resource without taking into account its dynamics. The extracted or harvested resource, \( H_j \), can be consumed or used as a raw material for industrial production. The maximization of profits, in a competitive market with free entry, needs the following condition:

\[ p_{H_j} = \omega_j \frac{L_{H_j}}{H_j} = \omega_j \frac{H_j}{\epsilon S_j} \]

(10)

where \( p_{H_j} \) is the price of the primary good and \( \omega_j \) is the salary in region \( j \).

**Industrial sector**

A firm in the industrial sector employs labour and raw materials to produce industrial goods, according to the production function:

\[ x_{ji} = \left( \frac{1}{\beta} \right) (l_{x_{ji}} - f)^{\sigma b_{ji}^{1-\alpha}, \quad 0 < \alpha < 1} \]

(11)

\[ b_{ji} = \left( \frac{\sigma - 1}{\beta_{1ji}^{\sigma} + \beta_{2ji}^{\sigma}} \right)^{\frac{\sigma}{\sigma - 1}} \]

(12)

where \( l_{x_{ji}} \) is labour used in producing variety \( i \) in region \( j \), and \( x_{ji} \) is the output; \( b_{ji} \) is an index of raw materials employed in the production of variety \( i \) in region \( j \); and \( b_{kji} \) is the primary good extracted in region \( k \) employed in region \( j \) production of variety \( i \). For simplicity we have assumed same elasticity substitution \( \sigma \) for primary goods. Parameter \( \beta > 0 \) is the marginal input requirement; and \( f \) is a fixed cost. Note that if \( \alpha = 1 \), the production function (11) is the same as the one proposed by Krugman (1980, 1991), which involves a constant marginal cost and a fixed cost,
giving rise to economies of scale. When \( \alpha \in (0, 1) \) the use of the raw material is necessary for production and increases labour productivity.

It is assumed that there are a large number of manufacturing firms, each producing a single product in monopolistic competition (Dixit & Stiglitz, 1977). Given the definition of the manufacturing aggregate (3), the elasticity of demand facing any individual firm is \(-\sigma\). The profit-maximizing price behaviour of a representative firm in region \( j \) is then:

\[
p_{ji} = \frac{\sigma}{\sigma - 1} \beta \left( \frac{w_j}{\alpha} \right) \frac{(P_{Hi})^{1-\alpha}}{P_{Hi}}
\]

(13)

Since firms are identical and face the same wage and the same price of raw materials within a region, manufactured good prices are equal for all varieties in each region, so the subscript \( i \) can be dropped. Consequently, \( p_j \) (\( j = 1, 2 \)) will refer to region \( j \) specific industrial good price. Equally, resource demand is equal for all firms in the same region \( j \), so we shall name the region \( j \) specific resource and labour demands per firm \( b_j \) and \( l_j \) (\( j = 1, 2 \)). Primary goods demand functions for the industrial sector in region 1 are:

\[
b_{11} = b_1^{1-\sigma} \left( \frac{1 - \alpha w_1(l_{s1} - f)}{\alpha} \right)^{\sigma} \quad \text{and} \quad b_{21} = b_1^{1-\sigma} \left( \frac{1 - \alpha w_1(l_{s1} - f)}{\alpha} \right)^{\sigma}
\]

(14)

and for region 2, \( b_{12} \) and \( b_{22} \) are mirror images of (14). Therefore:

\[
b_j = \frac{1 - \alpha w_j}{\alpha} \frac{(l_{xj} - f)}{P_{Hi}} \quad \text{for} \quad j = 1, 2.
\]

(15)

Comparing the prices of representative products in (13), we have:

\[
\frac{p}{p_1} = \frac{p_1}{p_2} = \frac{(w_1)^{\alpha} P_{Hi}}{(w_2)^{\alpha} P_{Hi}}^{1-\alpha}
\]

(16)

Because there is free entry in the industrial sector, a firm’s profits must equal zero. Using this condition and (13) and (15), it is obtained that:

\[
x_j = f \frac{\sigma - 1}{\beta} \alpha^\alpha (1 - \alpha)^{1-\alpha} \left( \frac{w_j}{P_{Hi}} \right)^{1-\alpha}
\]

(17)

\[
l_j = f [1 + \alpha(\sigma - 1)].
\]

(18)

The aggregate labour employed in the industrial sector of region \( j \) is \( L_{Ej} = n_j f [1 + \alpha(\sigma - 1)] \). Again, if \( \alpha = 1 \), we obtain the same expression as in Krugman’s model.

**Dynamics**

**Natural resources**

The regions are assumed to be endowed with a renewable natural resource (\( S_j \)) whose dynamics follows a logistic growth function (Clark, 1990):

\[
\dot{S}_j = g S_j \left( 1 - \frac{S_j}{CC} \right) - H_j
\]

(19)

where \( g > 0 \) is the intrinsic growth rate of the resource, that is, the rate at which the natural resource regenerates itself. The carrying capacity, \( CC > 0 \), is the maximum size of the resource that can be sustained. Because we are studying symmetric regions, both \( g \) and \( CC \) are assumed to be equal in both regions, which simplifies the model. Taking into account \( H_j \), given by (9),
into (19), the sustainable level of the resource (the positive steady-state level) is given by:

\[
S^*_j = \left(1 - \frac{\varepsilon}{g} L_{Hj}\right) CC > 0 \text{ if and only if } L_{Hj} < \frac{g}{\varepsilon}
\]  

(20)

which is globally stable for a given value of \( L_{Hj} \). Otherwise, the only globally stable steady state is the null one.

**Population mobility**

Workers are mobile between regions and choose to migrate if they gain in terms of individual welfare from doing so. We assume that \( L_1 + L_2 = 1 \) and, as is usual in NEG models, population reallocation follows the following dynamics:

\[
\dot{L}_1 = L_1(1 - L_1) \left(\frac{V_1}{V_2} - 1 \right)
\]  

(21)

where \( V_j \) is the indirect utility, defined as the ratio of nominal wage \( w_j \) to the Cobb–Douglas average price index across sectors (Sidorov & Zhelobodko, 2013; Forslid & Ottaviano, 2003):

\[
V_j = \frac{w_j}{(P_j)^\mu (P_{Hj})^{1-\mu}}
\]  

(22)

Therefore, the dynamic of the model will be driven by the differential system (19) for \( j = 1, 2 \) and (21).

**A NON-TRADABLE PRIMARY GOOD**

In this section we present the case of a non-tradable primary good. This is the case of fertile land, drinking water or highly perishable products, for example. To do this we assume that \( \nu \rightarrow \infty \).

When primary trade costs are unaffordable, households and firms can only purchase primary goods extracted in the local region. Thus, index prices \( P_{Hj} \) and \( P_{H2} \), defined in (8) and in its mirror image formula for region 2, and (16), become:

\[
P_{Hj} = p_{Hj} \text{ for } j = 1, 2
\]  

(23)

\[
p = \left(\frac{w_1}{w_2}\right) \left(\frac{S_1}{S_2}\right)^{(1-\alpha)}
\]  

(24)

where (10) has been taken into account. From (6) we have that, in region 1, households’ demand of primary good is:

\[
c_{H2} = 0 \text{ and } c_{H1} = C_{H1} = \frac{(1-\mu)w_1}{p_{H1}}
\]  

(25)

Mirror-image formulas hold for consumers in region 2.

Demand equations (14)–(15) can be simplified:

\[
b_{12} = b_{21} = 0 \text{ and } b_j = \frac{1 - \alpha}{\alpha} \frac{w_j}{p_{Hj}} (l_{sj} - f) \text{ for } j = 1, 2.
\]  

(26)
Short-run equilibrium
In the short-run equilibrium, households maximize their utility, industrial and primary firms maximize their profits, there is free entry in both sectors, and market clearing conditions hold for the three markets: labour, primary and industrial goods.

As a result of the free labour mobility assumption, the labour market clearing condition states that:

$$L_j = \int_0^{n_j} l_{xj} di + L_{Hj} = L_{Ej} + L_{Hj}$$ (27)

where $L_j$ is the total population of region $j$.

In the primary sector, total harvesting, $H_j$, must satisfy the demand for final consumption of the primary good (25) and the demands of the industrial firms for raw materials (26), that is:

$$H_j = L_j \left(1 - \mu \frac{w_j}{p_{Hj}} + n_j \frac{1 - \alpha}{\alpha} \frac{w_j}{p_{Hj}} (l_{xj} - f)\right)$$ (28)

Using equations (10), (18) and (27) we have that the primary sector clearing condition (28) implies:

$$L_{Hj} = \frac{\sigma - \mu [1 + \alpha (\sigma - 1)]}{\sigma} L_j$$ (29)

$$L_{Ej} = \frac{\mu [1 + \alpha (\sigma - 1)]}{\sigma} L_j$$ (30)

$$n_j = \frac{\mu}{\alpha f} L_j$$ (31)

Trade is balanced if and only if the following equation is satisfied:

$$TB = \rho \left(\frac{S_1}{S_2}\right)^{1-\alpha} \left(1 + \frac{L_1}{1 - L_1} \rho^{1-\sigma} \phi \right) - \rho^{1-\sigma} \left(\phi + \frac{L_1}{1 - L_1} \rho^{1-\sigma}\right) = 0$$ (32)

where $\phi = \rho^{1-\sigma}$, with $\phi \in (0, 1)$ is an index of the openness of trade. This equation has a unique positive solution. Using this solution and equation (24), the ratio of nominal wages can be obtained as a function of $\phi$, $L_1$, $S_1$ and $S_2$.

As we move from the short- to long-run equilibrium, however, some other features need to be taken into account. Workers are not interested in nominal wages but in real wages and they will migrate to the region with the highest welfare. Additionally, an increase in population will boost the use of natural resources for consumption and production, which provokes a dynamic adjustment of the natural environment. These two dynamic processes are explained in the following section.

Long-run equilibria
The usual agglomeration and dispersion forces of NEG literature (market size effect, competition and price index effects) arise in the model. As in Helpman (1998), a consequence of the non-tradability of the primary good and the free labour mobility is that the market size effect always dominates the competition effect. In addition, as a result of the dynamics of the natural resources, a new dispersion force arises, as is proved in Proposition 1.

Note that for a given level of $L_j$, the globally stable steady-state value of the natural resource, given in (20), becomes:

$$S_j^* = (1 - \epsilon \theta L_j)CC \text{ if } \epsilon \theta L_j < 1 \text{ otherwise } S_j^* = 0$$ (33)
where:
\[
\theta = \frac{\sigma - \mu[1 + \alpha(\sigma - 1)]}{gDs}
\]  
(34)

and (29) have been used.

Thus, due to the role played by the workforce in the resource extraction, a higher population, \(L_j\), tends to reduce the level of the sustainable natural resource \((S^*_j > 0)\). The same can be said for the extractive productivity parameter in the primary sector, \(e\). The following proposition establishes the consequences for wages and primary good price.

**Proposition 1**: When the population increases in one region, natural resource dynamics leads to:

(i) lower nominal wages; and

(ii) an increase in the price of primary goods and the industrial price index in that region.

**Proof**: See Appendix A in the supplemental data online.

This is the resource effect, and it has two channels that encourage dispersion through the consumers utility. Property i stands for the linkage between the primary and the industrial sector, and depends on \(\alpha\). Property ii affects the cost of living and its strength depends on \(\mu\).

Despite the similarities, the resource effect is different to the effects derived by Helpman (1998) and Ottaviano and Puga (1998). In these other models the dispersion forces are driven by region-specific supplies of the non-tradable good (or factors), which are fixed stocks. Thus, an increase in the population diminishes the stock per capita (per firm), so raising the price. In the model developed in this paper, the primary good is extracted or produced; it is not fixed. An increase in the population does not change the ratio \(H_j/L_j\), in the short run, due to the simultaneous increase in the extractive labour force (see equations (9) and (29)). However, in the long run, the steady states stock decreases, and so, therefore, does the ratio \(H_j/L_j\). The resource dynamic is essential for the existence of the resource effect.

Equation (21) can be simplified by replacing (22), and making use of \(P_1\) definition in (7), its mirror image for \(P_2\), (10), (23), (24), (31) and (32). Thus, the dynamic evolutions of the stocks of the natural resource and population between the two regions are driven by equations (19) with \(j = 1, 2\) and (21) and can be rewritten as:

\[
\dot{L}_1 = L_1(1 - L_1) \left[ \frac{S_1}{S_2} \right]^{1-\mu a - \mu(1-\alpha)/(1-\sigma)} - \frac{p^{\mu(1-2\alpha)/(1-\sigma)} - 1}{1 - S_1} 
\]  
(35)

\[
\dot{S}_1 = gS_1 \left( 1 - \frac{S_1}{CC} \right) - e g \theta S_1 L_1
\]  
(36)

\[
\dot{S}_2 = gS_2 \left( 1 - \frac{S_2}{CC} \right) - e g \theta S_2 (1 - L_1)
\]  
(37)

where \(\theta\) is defined by (34); and \(p\) is a function of the population size, according to equation (32).\(^5\) A long-run equilibrium is a stationary point of the dynamic equation system (35–37), where workers do not have incentives to move from one region to the other and natural resource stocks remain constant. Furthermore, because we are studying a renewable natural resource, we are interested in the set of parameters that allows at least one long-run sustainable solution \((S^*_j > 0)\). To
ensure this, we assume hereinafter that:

$$\epsilon \theta < 2.$$  \hfill (38)

If parameters satisfy the sustainability condition (38), then there exists a symmetric interior equilibrium, characterized by the following values, where population is equally distributed:

$$L_1^* = 1/2, \quad S_1^* = S_2^* = \left(1 - \epsilon \frac{\theta}{2}\right) CC, \quad p^* = 1$$  \hfill (39)

Note that if $\epsilon \theta < 1$, the symmetric (interior) equilibrium coexists with the following two agglomeration (boundary) equilibria:

$$L_1^* = 1, \quad S_1^* = (1 - \epsilon \theta) CC, \quad S_2^* = CC, \quad p^* = \phi^{-1/\alpha} (1 - \epsilon \theta)^{-(1-\alpha)/\alpha}$$  \hfill (40)

and

$$L_1^* = 0, \quad S_1^* = CC, \quad S_2^* = (1 - \epsilon \theta) CC, \quad p^* = \phi^{1/\alpha} (1 - \epsilon \theta)^{(1-\alpha)/\alpha}$$  \hfill (41)

When $\epsilon \theta \geq 1$, the agglomeration equilibria become:

$$L_1^* = 0, \quad S_1^* = CC, \quad S_2^* = 0, \quad p^* = 0$$  \hfill (42)

Mirror-image values are obtained for $L_2^* = 0$.

**Stability properties**

According to (39–42), economic activity can be equally distributed between the regions or concentrated in one of them. Which equilibrium will prevail depends on the stability properties, expressed in terms of the parameters of the model, in the following proposition.

**Proposition 2:** The symmetric interior equilibrium is locally stable if the following condition is satisfied:

$$\phi > \max \{\phi^B, \phi^H\}$$  \hfill (43)

with

$$\phi^B = 1 - \frac{(\sigma - 1)(\sigma(1 - \mu \alpha) - \mu(1 - \alpha))\epsilon \theta}{(2\sigma - 1)\mu(1 - \epsilon \theta/2) + (\sigma - 1)(1 - \mu - \mu(1 - \alpha))\epsilon \theta/2}$$

and

$$\phi^H = 1 - \frac{2\sigma(\sigma - 1) g(1 - \epsilon \theta/2)}{(2\sigma - 1)\mu + (\sigma - 1)g(1 - \epsilon \theta/2)}.$$

Meanwhile, the agglomeration equilibria (40 and 41) are locally stable (stable nodes) if the following condition holds:

$$\phi < \phi^S = (1 - \epsilon \theta)\mu(2\sigma - 1) \left[\sigma(1 - \mu \alpha) - \mu(1 - \alpha)\right]$$  \hfill (44)

and agglomeration equilibrium (42) is always unstable.

**Proof:** See Appendix A in the supplemental data online.

In the previous proposition the superscript B is for ‘break’ and the superscript S is for ‘sustain’ (maintaining the labelling used by Fujita et al., 2001). The superscript H is for Hopf, since at this point a Hopf bifurcation arises, as will be shown below.
Condition (43) defines a region of stability for the symmetric equilibrium (the shaded region in Figure 1) in the space of parameters $\epsilon$ and $\phi$. This stability region is not empty, although it can be greater or smaller depending on the parameters of the model. The downward sloping curve $\phi^B$ in the $(\epsilon, \phi)$ space is the boundary for the pitchfork bifurcation, and $\phi^H$, upward sloping, is the boundary for the Hopf bifurcation. Both curves intersect at point $\bar{\epsilon}_7$.

Figure 1 represents the stability condition (43) for parameters $\sigma = 2$, $\alpha = 0.6$, $\mu = 0.8$ and $g = CC = 1$.

The symmetric equilibrium (39) is not necessarily the only interior equilibrium for the system (35)–(37). According to the value of the parameters, there could be two more interior equilibria around the symmetric one. The following proposition proves this result.

**Proposition 3:** If $\phi^B, \phi^S \in (0, 1)$ and $\epsilon < \bar{\epsilon}$, an increase in the openness of trade leads to:

(i) a sudden change from agglomeration to dispersion for low levels of the extractive productivity, $\epsilon < \min \{\bar{\epsilon}, \bar{\epsilon}\}$; and

(ii) a smooth change from agglomeration to dispersion for high levels of the extractive productivity, $\bar{\epsilon} < \epsilon < \bar{\epsilon}$

where $\bar{\epsilon} > 0$ is the intersection point of $\phi^B$ and $\phi^S$.

**Proof:** See Appendix A in the supplemental data online.

Proposition 3 proves that as transport cost decreases ($\phi$ increases) the stability of the symmetric equilibrium changes. This prominence of transport costs is not new in NEG models. What is new in our model is the emergence of a second actor: the extraction productivity in the primary sector, measured by $\epsilon$. This parameter will determine if the transition is sudden (a subcritical pitchfork bifurcation) or smooth (a supercritical pitchfork bifurcation). Both phenomena are observed in the real world. As reported by Andrew et al. (2003), the rapid movement of fishing efforts (fleet, fishermen, processing facilities, etc.) to unexploited regions has occurred in many world fisheries. In contrast, a slow depopulation has been observed as the consequence of deforestation or soil fertility decline (Dazzi & Papa, 2013). Parameter $\epsilon$ plays an important role in environmental economic models that use the catch per unit-effort resource production function. Its value depends on both the natural resource in question and the technology employed. Therefore, these two facts matter for a sudden or a smooth structural change in the geographical distribution of the economic activity.

Figure 1. Stability region of the symmetric equilibrium.
Additionally, the incorporation of the dynamics of natural resources into the original core-periphery model leads to the appearance of periodic solutions, as is proved in the following proposition.

**Proposition 4:** When $\phi^i < \phi < \phi^H$ migration flows adopt a cyclic behaviour, where:

$$\phi^i = 1 - 2\sigma \frac{\delta^i}{1 + \delta^i}$$

and $\delta^i$ is defined as in Appendix A in the supplemental data online.

**Proof:** See Appendix A.

Note that $\phi^H$ and $\phi^i$ intersect at point $\bar{\epsilon}$. Thus, for $\epsilon > \bar{\epsilon}$ passing from the left to the right of curve $\phi^H$, there are two complex conjugate eigenvalues that move from having a negative real part to having a positive real part, and the symmetric equilibrium loses its local stability. The proposition shows the emergence of cyclic behaviour (a Hopf bifurcation) for relatively high values of the extractive productivity ($\epsilon > \bar{\epsilon}$).

The existence of cyclic behaviour is new to the literature of CP models in continuous time. However, Agunias and Newland (2007) and the report of the European Migration Network (2011) recognize the existence of circular migration. In some cases it is due to environmental issues (Rauscher, 2009). Proposition 4 points again to the extraction productivity, $\epsilon$, as a key parameter ($\epsilon > \bar{\epsilon}$), together with transport costs.

The following subsection describes the process of agglomeration–dispersion of the economic activity between two regions, focusing on the role of transport cost and primary sector productivity in the stability properties of the equilibria.

### The role of transport cost and extraction productivity

The first result that stands out is that as the transport cost decreases ($\phi$ increases) the symmetric equilibrium changes from unstable to stable (Proposition 2). This is in contrast to the results found in the original CP model but in line with Krugman and Elizondo (1996), Helpman (1998) and Murata and Thisse (2005).

In the transition between instability and stability, the extraction productivity of the primary sector becomes important. As pointed out above, different values of $\epsilon$ can change the bifurcation pattern. Figure 1 gives a clear view of the role of $\epsilon$. For a given transport cost, the larger the value of $\epsilon$, the closer we are to the stability region of the symmetric equilibrium. Therefore, the dispersion force is a direct function of $\epsilon$.

Note that this result is the opposite to what Tabuchi, Thisse, and Zhu (2016) find when they analyze an increase in the industrial productivity through a fall in the marginal labour requirement. Two differences are driving these opposite results. First, the model proposed by Tabuchi et al. has migration costs. This implies that the size of the gap between real wages matters in their model and not in ours. Thus, when industrial productivity increases in Tabuchi’s model, the real wage gap widens, overcoming the effect of migration costs and giving place to further agglomeration. In our model the equilibrium implies real wage equalization, so an increase in the extraction productivity does not have a direct impact on prices through this channel. Second, in our model, the extraction productivity has a second channel through which it can affect the equilibria: it has an indirect impact through the long-run stock of natural resources. This channel is not present in Tabuchi et al. Thus, in the case of $L_1 \neq 1/2$ an increase in the extraction productivity can change the ratio of indirect utilities, shifting dynamics and the possible equilibria. Hence, while an increase in the industrial productivity tends to magnify regional disparities, an increase in the extraction productivity tends to mitigate or even revert these disparities when there are no migration costs.
The process depicted by Figure 2, the subcritical case, is characterized by a sudden change in spatial configuration (Fujita et al., 2001). This is because the non-symmetric interior equilibria connecting the agglomeration and symmetric solutions are unstable. In this case, the bifurcation diagram has a Krugman tomahawk shape, but the stability pattern is inverted.

If the extraction productivity of the primary sector is low enough, for a value of \( \epsilon < \min \{ \tilde{\epsilon}, \bar{\epsilon} \} \) (subcritical bifurcation), then dispersion forces are weak, and for low values of \( \phi \) (such that \( \phi^H < \phi < \phi^B \)), agglomeration equilibria are stable. As transport costs decrease the equilibrium moves to the right in Figure 2, and a subcritical bifurcation takes place at \( \phi^B \). The peculiarity of this pattern is that for \( \phi \in (\phi^B, \phi^S) \) both agglomeration and dispersion equilibria are locally stable. This occurs precisely because dispersion forces are weak, so when the distribution of the economic activity is near to being fully agglomerated, the size of the market can still overcome the dispersion forces, even at relatively low transport costs. However, when the distribution of the economic activity is near the symmetric equilibrium, the market size effect is not very strong because the difference between the sizes of the markets is small. Therefore, dispersion forces can overcome agglomeration forces.

The process depicted by Figure 3, the supercritical case, is characterized by a smooth change in the spatial configuration. This is because the interior non-symmetric equilibria are stable and connect the agglomeration and dispersion solutions. The bifurcation diagram closely resembles the one derived by Helpman (1998).

If the extraction productivity is high enough, such that \( \tilde{\epsilon} < \epsilon < \bar{\epsilon} \) (supercritical bifurcation), and the transport cost is \( \phi^H < \phi < \phi^B \), agglomeration equilibria are stable. In this case, dispersion forces are stronger, so \( \phi^S \) and \( \phi^B \) are lower than in the subcritical case. As transport costs decrease the equilibrium moves to the right in Figure 3, and a supercritical bifurcation takes place at \( \phi^B \). The main difference is that for a \( \phi \in (\phi^S, \phi^B) \) both agglomeration and dispersion equilibria are now locally unstable while the other two non-symmetric interior equilibria are locally stable. Why does this pattern occur? Dispersion forces are strong, so agglomeration equilibria become unstable at a low value of \( \phi \). At this point, however, the market size effect is still strong due to high transport costs, so the symmetric solution is also unstable. Meanwhile, the non-symmetric equilibria are stable because if a new firm decides to move to the most populated region, the high extractive productivity in the resource sector causes a sharp increase in the primary prices and dispersion forces activate. In contrast, if a firm decides to move to the less populated region, the high extractive productivity in the resource sector causes a sharp increase in the primary prices and dispersion forces activate.

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Figure 2. Subcritical pitchfork bifurcation – parameter values: \( \sigma = 2, \alpha = 0.6, \mu = 0.8, g = CC = 1 \) and \( \epsilon = 2.2 \).
populated region, this firm will have to pay high transport costs to have access to the larger market, and agglomeration forces are set in motion.

When $\phi < \bar{\phi}^H$ and $e > \bar{\epsilon}$, the openness of trade is not high enough to guarantee the stability of the symmetric equilibrium, so this high transport cost triggers an agglomeration process. However, the population growth together with a high extraction productivity (high value of $e$) accelerate the depletion of the natural resource. The resource dynamics boost the dispersion forces, first by slowing down the migration flow and finally by reversing it, all of which give rise to a circular behaviour. This is consistent with Robinson, Albers, and Williams (2008) who, in a different framework, find that the spatial characteristic of the extraction of a renewable resource ultimately results in cyclical dynamic extraction.

What we find with a renewable and extractable resource is that households move to the region with the higher real wages, and as the market gets bigger, the agglomeration of persons and firms accelerates, so raising the demand for primary goods. The primary sector extracts more natural resources to cope with the increase in demand, compromising its long-term stock and the level of future extractions. Ultimately, the scarcity of the resource raises the primary prices enough to reverse the migration process. This scheme resembles the chase-and-flee cycle of location of Rauscher (2009), but through a different channel.9

The migration flow caused by this circular behaviour is compatible with some of the ideas outlined on circular migration in the migration and economic labour literature. Newland (2009) refers to this phenomenon as a seasonal or periodic migration for work, for survival or as a life-cycle process. Additionally, there have been some attempts to quantify the importance of circular migration and its impact in the origin and the destination countries (e.g., see Constant & Zimmermann, 2012; and Agunias & Newland, 2007, for other references).

A TRADABLE PRIMARY GOOD

In this section we present the case of a tradable primary good. To simplify the analysis we assume that the primary good is tradable at the same transport cost of industrial goods, that is, $v = \tau$. 
Short-run equilibrium

The three markets (labour, industrial and primary goods) clear. Replicating the analysis followed in the third section, it is obtained that (see Appendix B in the supplemental data online for a comprehensive explanation):

\[ L_{E_1} w + L_{E_2} = \mu \frac{1 + \alpha(\sigma - 1)}{\sigma} (L_1 w + L_2) \] (47)

\[ L_{H_1} w + L_{H_2} = \frac{\sigma - \mu [1 + \alpha(\sigma - 1)]}{\sigma} (L_1 w + L_2) \] (48)

\[ n_j = \frac{L_{E_j}}{f[1 + \alpha(\sigma - 1)]} \quad \text{for} \quad j = 1, 2. \] (49)

where \( w \equiv w_1/w_2 \). Moreover, trade between the two regions is balanced if and only if:

\[ TB = \mu \left( \frac{z_{12}}{1 + z_{12}} L_2 - \frac{1}{1 + z_{11}} L_1 w \right) + \left(1 - \mu\right) \left( \frac{q_{12}}{1 + q_{12}} L_2 - \frac{1}{1 + q_{11}} L_1 w \right) \]

\[ + \frac{(1 - \alpha)(\sigma - 1)}{1 + \alpha(\sigma - 1)} \left( \frac{q_{12}}{1 + q_{12}} L_{E_2} - \frac{1}{1 + q_{11}} L_{E_1} w \right) = 0. \] (50)

where \( q_{11} \) is the ratio of region 1 expenditure on local primary good to that on primary good from region 2; and \( q_{12} \) is the expenditure of region 2 on region 1 primary good with respect to the primary good from region 2. The first term of equation (50) is the difference between industrial exports and imports of region 1; the second term is the difference between primary exports and imports of region 1 for final consumption; and the third term is the difference between primary (raw material) exports and imports of region 1 to be used as inputs by the industrial firms. Note that if the last two terms of equation (50) vanish, which is the case if the primary good were not tradable, equation (50) would reduce to (32).

The symmetric equilibrium (39) satisfies equation (50) and the derivative at this point is:

\[ \frac{\partial TB}{\partial w} (L_1^*, S_1^*, S_2^*, w^*) = \frac{\phi(2\sigma - 1 + \phi)}{(1 + \phi)^2} \]

\[ + \frac{\phi \Psi^*(\phi)}{(1 - \phi)^2 (1 + \phi)} [(1 + \phi)^2 + 2(\sigma - 1)(2\alpha\phi + 1 - \phi)] \]

\[ > 0 \]

with \( L_1^* = 1/2, S_1^* = S_2^* = S^* = (1 - e(\theta/2))CG, w^* = 1 \) and \( \Psi^*(\phi) > 0 \) is (94) evaluated at the symmetric equilibrium. Therefore, for a given value of \( \phi \), equation (50) implicitly defines \( w \) as a function of \( L_1, S_1 \) and \( S_2 \) in a neighbourhood of the symmetric equilibrium.

Using the implicit differentiation in (50), we obtain, at the symmetric equilibrium, that:

\[ \frac{\partial w}{\partial L_1} = \frac{-4[1 - \Psi^*(\phi)(1 + \phi)/(1 - \phi)]}{(2\sigma - 1 + \phi)/(1 + \phi) + [(1 + \phi)^2 + 2(\sigma - 1)(2\alpha\phi + 1 - \phi)]\Psi^*(\phi)/(1 - \phi)^2} \] (51)

which can be negative or positive, depending on the value of \( \phi \). That is:

\[ \frac{\partial w}{\partial L_1} \leq 0 \quad \text{if and only if} \quad \phi \leq \hat{\phi} = \frac{\sigma(1 - \mu) - \mu[1 + \alpha(\sigma - 1)]}{\sigma(1 - \mu) + \mu[1 + \alpha(\sigma - 1)]} < 1 \] (52)
In contrast to what happened in the third section, now if the stock of the natural resources remains constant, the competition effect could be strong enough to dominate the market size effect for high values of transport costs ($\phi$ low enough). Additionally, implicit differentiation in (50) with respect to $S_1$ and $S_2$ gives, at the symmetric equilibrium:

$$\frac{\partial w}{\partial S_1} = \frac{1}{S^s} \frac{2(\sigma - 1)[1 + \Psi^*(\phi)(1 - \alpha)(1 + \phi)/(1 - \phi)]}{2\alpha - 1 + \phi + [(1 + \phi)^2 + 2(\sigma - 1)(2\alpha\phi + 1 - \phi)]\Psi^*(\phi)(1 + \phi)/(1 - \phi)^2} > 0$$  (53)

The resource effect is reinforced. The original mechanisms described in Proposition 1 remain, but a new one appears. Note that now a reduction in the primary price due to an increase in $S_1$ encourages exports of region 1 that must be compensated for with an increase in nominal wages of this region. All these mechanisms go in the same direction.

**Long-run equilibrium**

In the long run the stock of natural resources does not remain constant; its temporary evolution obeys the differential equation (19) and population migrates from one region to the other according to (21). For the case of a tradable primary good, the ratio of indirect utilities is:

$$\frac{V_1}{V_2} = \frac{w_1}{w_2} \left( \frac{P_1}{P_2} \right)^{-\mu} \left( \frac{P_{H1}}{P_{H2}} \right)^{-\left(1-\mu\right)}$$  (54)

where $P_{Hj}$ is the resource price index for region $j = 1, 2$. From equations (8), its mirror image for region 2, and (54) it is clear that when the ratio $S_1/S_2$ decreases, the ratio of indirect utilities will diminish; and this result is equivalent to property ii in Proposition 1.

Hence, the differential equations system (19) for $j = 1, 2$ and (21) now takes the form:

$$\dot{L}_1 = L_1(1 - L_1)[\Delta(w, S_1, S_2) - 1]$$  (55)

$$\dot{S}_1 = S_1 \left[ g \left( 1 - \frac{S_1}{CC} \right) - \epsilon L_{H1} \right]$$  (56)

$$\dot{S}_2 = S_2 \left[ g \left( 1 - \frac{S_2}{CC} \right) - \epsilon L_{H2} \right] = S_2 \left[ g \left( 1 - \frac{S_2}{CC} \right) - \epsilon \left( g\theta L_1 - L_{H1} \right) w + g\theta(1 - L_1) \right]$$  (57)

where $\Delta(w, S_1, S_2)$ is defined in Appendix B in the supplemental data online (see equation 99); $L_{H1} = L_1 - L_{E1}$; $L_{H2} = (g\theta L_1 - L_{H1})w + g\theta(1 - L_1)$ according to equation (48); and $w$ is defined by the balanced trade equation (50) as a function of $L_1, S_1$ and $S_2$.

The three steady states defined in (39)–(41) are also steady states of the new system (55)–(57). However, the stability pattern of the symmetric equilibrium may differ from the case of a non-tradable primary good.

**Stability properties**

The shaded region in the examples of Figure 4 represent the stability regions of the symmetric equilibrium in the space $(\epsilon, \phi)$ for the different sets of parameters.

Note that depending on the value of the parameters, several bifurcation patterns may appear. From Figures 4(a–d), the predominant pattern for the symmetric equilibrium is the one that goes...
from stable to unstable as transport costs decrease. Additionally, some regularities are observed and are worthy of mention.

First, when transport cost are very low, the symmetric equilibrium is unstable for all values of \( \epsilon \in (0, 2/\theta) \). Because the primary good now can be exported to the other region (at a low transport cost), the advantage of having a lower primary price is limited. Second, when \( \epsilon \) is low, the symmetric equilibrium is also unstable. This is due to the interaction between the tradability of the primary good and a low resource effect, caused by a low extractive productivity. Third, in the lower-right quadrant in the \((\epsilon, \phi)\) space, transport costs are high and the tradability of the primary good is limited, then, as happened in the third section, the symmetric equilibrium is unstable.

Finally, if the transport costs of the primary goods were different from those of the industrial goods, similar results could be obtained, but the interaction between the agglomeration and dispersion forces would depend on how these two transport costs relate and vary.

Figure 4. Stability region of the symmetric equilibrium (tradable primary good): (a) \( \sigma = 7, \alpha = 0.5, \mu = 0.5, g = 0.5, CC = 1 \); (b) \( \sigma = 7, \alpha = 0.2, \mu = 0.5, g = 0.5, CC = 1 \); (c) \( \sigma = 7, \alpha = 0.5, \mu = 0.5, g = 1, CC = 1 \); and (d) \( \sigma = 7, \alpha = 0.5, \mu = 0.2, g = 0.5, CC = 1 \).
CONCLUSIONS

This paper presents an extension of Krugman’s (1991) CP model and attempts to provide a more comprehensive modelization of the traditional sector, usually treated as residual. The results allow a better understanding of the migratory processes observed in resource-based economies. The model incorporates two key features of the agricultural sector: the dynamics of the renewable natural resources, and the possibility of using raw materials as inputs in the industrial production. It was assumed that the primary good is not directly tradable between regions in order to isolate the resource effect that arises in the model. The paper extended the analysis to the case of a tradable primary good. Another major difference between the present model and the original CP model is the free labour mobility between sectors.

The CP model presented in this paper has all the effects of the traditional NEG models: market size effect, price index effect and competition effect. Once we incorporate the dynamics of the natural resources into the analysis, a new dispersion force arises: the resource effect. Under certain conditions, this dispersion force overcomes the agglomeration ones driven by the industrial price index and the market size effect, making the symmetric equilibrium stable. In real examples worldwide, it is observed that this force provokes environmentally induced migration (e.g., Andrew et al., 2003; Kirby, 2004; Jouanjean et al., 2014).

If the primary good is not tradable, the effect of transport costs on the stability pattern of the traditional CP models is reversed. For high transport costs, one might expect agglomeration to take place (if the new dispersion force is not too strong). However, as transport cost decreases, imports become cheaper and the advantage of being in the largest region diminishes. For example, the construction of new roads increases the profitability of the exploitation of forest and soil in distant areas in Laos, the Philippines, Paraguay, Brazil, Peru, Panama and Bolivia, encouraging the expansion and dispersion of the economic activity (Laurance et al., 2009; Reymondin et al., 2013).

Our model also gives insights into the transition between agglomeration and dispersion of the economic activity and highlights the role of the extraction productivity in the primary sector. The conditions for a pitchfork bifurcation and a Hopf bifurcation are determined. Depending on the productivity of the primary sector, the pitchfork bifurcation can be sub- or supercritical, and these two patterns illustrate different processes. On the one hand, strong agglomeration forces (subcritical) imply a sudden change in the spatial distribution of the economic activity, as in the rapid shift that took place in the exploitation of the sea urchin fisheries in Chile (Andrew et al., 2003). On the other hand, strong dispersion forces (supercritical) imply a smooth change, as observed in the slow depopulation driven by the decline in soil fertility in Italy (Dazzi & Papa, 2013).

Another important result in our paper is the existence of a Hopf bifurcation, which makes the appearance of a branch of periodic solutions feasible, so introducing cyclic behaviour in the dynamics. When the extraction productivity of the primary sector is too high, economic activity will tend to agglomerate in one region until the primary good becomes too expensive, and then a dispersion process takes place. However, due to the high extraction productivity, the stock of the resource takes longer to renew and, while this happens, more firms continue to arrive in the other region, so agglomeration is now taking place in this region. This is a completely new result in CP models in continuous time.

If the primary good is tradable, several bifurcation patterns may appear, depending on the value of the parameters. Also, some regularities are observed. First, reductions in the transport costs of the primary goods weaken the dispersion forces associated with the resource, then, for low values of transport cost, the dispersion equilibrium is unstable. Second, for low values of the extraction productivity, the symmetric equilibrium is also unstable. In most cases, the symmetric equilibrium goes from stable to unstable as the openness of trade increases.
NOTES

1 The mobility of labour between sectors has been addressed by Puga (1998), who assumes free mobility across sectors and regions. Labour dynamics in a specific sector of a region is driven by the relation between the real wage in that sector and a weighted average of the real wages in the other sector (within the same region) and real wages in the other region. In the present paper, for simplicity, we have assumed that nominal wages within a region adjust immediately to become equal in the two sectors. Although the dynamics would be more complex, the steady-states equilibria would remain the same.

2 As reported by Adhikari, Nagata, and Adhikari (2004), there still exist some examples of free access to forest resources in Nepal. Moreover, fisheries have proven difficult to regulate and an open-access externality of reasonable size still exists in Nordic fisheries (Waldo et al., 2016). Poor regulation has resulted in both stock depletion and low economic returns, leading to the well known ‘Tragedy of the Commons’. Fishery, forestry, irrigation, water management, animal husbandry, biodiversity and climate change are the usual areas where the ‘tragedy’ has arisen (Laerhoven & Ostrom, 2007).

3 In Fujita et al. (2001), \( \dot{L}_1 = L_1 (V_1 - \bar{V}) \), where \( \bar{V} = L_1 V_1 + (1 - L_1) V_2 \) is the weighted average of indirect utilities. A simple manipulation derives that \( \dot{L}_1 = L_1 (1 - L_1) (V_1 - V_2) \), which is equivalent to (21) if we divide by \( V_2 \).

4 For this equation, see Appendix A in the supplemental data online. From now on, all the long derivations and proofs are presented online.

5 After some manipulations, we have that:

\[
\frac{P_1}{P_2} = \left( \frac{(L_1/L_2) \rho^{1-\alpha} + \phi}{(L_1/L_2) \rho^{1-\alpha} + 1} \right)^{1/(1-\alpha)} = \rho^{\alpha/(1-\alpha)} \left( \frac{S_1}{S_2} \right)^{(1-\alpha)/(1-\alpha)}
\]

6 On replacing the symmetric equilibrium \( (L_1^* = 1/2, S_1^* = S_2^* = (1 - \epsilon \theta/2)CC) \), and the agglomeration equilibria \( (L_1^* = 1, S_1^* = (1 - \epsilon \theta)CC, S_2^* = CC) \) and \( L_1^* = 0, S_1^* = CC \) and \( S_2^* = (1 - \epsilon \theta)CC \), in equation (32), the equilibrium price \( \rho^* \) is obtained. Thus, it is easy to confirm that the three-differential-equation system (35)–(37) vanishes for (39) as well as for (40)–(42).

7 \( \bar{\epsilon} = (\sigma - 1)(1 - \alpha) + \sigma(2 + \theta) - \sqrt{\sigma - 1} \left( 1 - \sigma \right)^2 + \theta \left[ 2(1 - \alpha)(\sigma - 1) + \sigma(2 + \theta) \right] / \left[ \sigma(\sigma - 1)(1 - \alpha) \right] > 0 \)

8 If in our model there were a real wage gap differential, and holding constant the stock of natural resources, an increase in \( \epsilon \) would also widen this gap, as in Tabuchi et al. (2016), and through the same direct channel. Nevertheless, the only possible equilibria where real wages are not equalized (in our model) are the agglomeration ones, where concentration has already reached its maximum.

9 In Rauscher’s (2009) chase-and-flee cycle, people preferred a clean and healthy environment, so they decided to stay away from industrial (polluting) activities; but they are chased by the industries, which want to locate close to the market.

10 Note that \( (\partial \phi / \partial \alpha) < 0 \), which implies that an increase in \( \alpha \) reinforces the market size effect. If \( \alpha \) increases, the linkages between the two sectors weaken. Therefore, there is a shift of firm expenditures from primary goods (coming from both regions) to labour (a completely local factor). This reinforces the effect of the market size.

ACKNOWLEDGEMENTS

Thanks are due to the anonymous reviewers for their very helpful comments.
DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

FUNDING

This work was supported by the COST Action IS1104 ‘The EU in the New Economic Complex Geography: Models, Tools and Policy Evaluation’ and the Secretaría de Estado de Investigación, Desarrollo e Innovación [grant numbers ECO2014-52343-P and ECO2017-82227-P].

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