Technology, agglomeration, and regional competition for investment

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Abstract. Competition for firms by region has a long-standing history, and the academic literature has debated whether such competition is efficient. We develop a model that explores technology development by firms facing regional competition for their investment and examine the endogenous determination of region policy, firm technology, and agglomeration externalities. We find a new source of inefficiency – regional competition leads firms to inefficiently distort their development and selection of production technology to improve their standing in the regional competition for their investment. We show that these inefficient firm decisions on technology and location can also weaken agglomeration externalities. JEL classification: H71, L2

Technologie, agglomération et concurrence régionale pour l'investissement. La concurrence pour les entreprises entre les régions a une longue histoire, et la littérature spécialisée a beaucoup débattu pour déterminer si une telle concurrence est efficiente. On développe un modèle qui explore le développement de technologie par des entreprises qui font face à une concurrence interrégionale pour leur investissement, et qui examine la détermination endogène de la politique régionale, de la technologie de l'entreprise, et des effets externes d'agglomération. On découvre une nouvelle source d'inefficacité – la concurrence interrégionale entraîne les entreprises à modifier leur développement et leur choix de technologie de production pour améliorer leur capacité à tirer leur épingle du jeu dans la concurrence interrégionale pour leur investissement. On montre que ces décisions inefficaces des entreprises tant pour la technologie que pour la localisation peuvent aussi réduire les effets externes d'agglomération.

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1. Introduction

Previous economic literature has examined a number of issues connected with regional competition for investment – most notably, whether competition among regions promotes or impedes efficient location of production. While such competition gets substantial media attention, reports of recent high-profile cases have also highlighted another phenomenon connected with the firms receiving incentives – namely, the alterations in production techniques that firms undergo in locating to new regions offering these incentives. For example, in the mid-1990s Caterpillar closed a large plant in Pennsylvania and split its production into four new smaller plants in Mississippi, North Carolina, Kentucky, and South Carolina. According to published reports on the case, the move was precipitated by Caterpillar's desire to take advantage of substantial tax-relief incentives that had been extended.[1] The aforementioned Southern states had been attempting to lure Caterpillar for some time, yet Caterpillar was reluctant to relocate because the relatively small pool of skilled machinists in these states was apparently deemed insufficient to support a 'standard issue' Caterpillar plant. This fact notwithstanding, Caterpillar was eventually able to revise its production process into smaller operations that could be dispersed across these four separate locations.

Another example involves the well-known Mercedes Benz automobile plant locating in Alabama in the mid-1990s after intense competition for the plant by many states offering very large incentive packages. Experts in the field, as well as Mercedes' own managers, stressed that Mercedes' location in Alabama came with a concomitant change in production process connected with a region with a relatively unskilled labour pool. For example, whereas production lines in Germany were already highly automated at the time, the Alabama factory had robots involved only in installing windows (*Business Week*, 31 March 1997) As summarized by Bill Taylor, vice-president of Operations at the plant, 'Plant automation was kept simple . . . We kept the process of building an automobile as simple as possible because we already had all these variables – new product, new people [most of whom are new to the auto industry], new plant . . . People can only bite off and digest so much at a time' (*Industry Week*, 7 October 1996). Thus, relocation to a completely new region apparently involved a substantial alteration of the production process to match the characteristics of the region.

Important for our purposes is the potential for some production process development to take place *before* regions begin to bid for the firms' investments, not simply after location. It seems unlikely that companies would pick locations where their production process would be so different from current operations (as the above examples indicate) without prior research into the alterations that would be beneficial and/or necessary. In fact, many firms use a combination

1 Caterpillar was also involved in protracted disputes with its unionized labour force in the northern U.S. states and the 'right-to-work' provisions in southern states were also likely part of their attraction to relocation possibilities. See Aron (1997) for more details on this example.

of internal and independent site selection consultants to confidentially explore alternative locations prior to announcing their intention to site a plant and the locations they will consider. Such activities constitute a form of prior research and also involve efforts to understand and develop the firm's flexibility across various components of its operations.[2]

The above examples point to a number of important issues we will address in this paper that have been ignored in the previous literature. First, the production technologies that firms ultimately develop may themselves be endogenously determined by the subsequent regional competition for investment. In particular, the desire of firms to elicit favourable tax concessions may substantially impact the trajectory of technical progress and even lead to inefficient production and location decisions by firms. Second, the inefficiencies just noted may be compounded, in turn, by the agglomeration externalities that are often inherent to industrial development.

More specifically, we introduce endogenously determined technical innovation into a model of regional competition for investment in which agglomeration externalities may be present. Our analysis begins by first considering a benchmark model of regional competition in which the productive capabilities of firms are exogenously determined. Firms choose production plans (given their fixed capabilities) and their location to maximize profits, while regions choose tax packages to maximize a region's welfare. We show that if regions have a sufficiently rich set of tax policy instruments and extra-regional externalities are negligible, then competition will necessarily lead to Pareto-efficient location and production decisions by firms.

We then relax the assumption of exogenously specified technology and provide firms with the option to pursue exploratory research activities, including traditional research and development (R&D), in a stage prior to the competition between regions for firm location investment. The ability of firms to alter their productive capabilities in advance of the regional competition stage proves to be far from innocuous. Indeed, we show that it enables firms to distort the subsequent regional competition in a manner that will often induce Pareto inefficiency, even when regions have access to a comprehensive arsenal of tax policy instruments. The intuition is that firms are able to extract more favourable tax breaks when there is stronger competition amongst regions to secure the firm as a 'resident.' This provides firms the incentive to choose technologies that do not strongly favour one region at the expense of all others, but may be generally inferior from an efficiency standpoint. As a result, regional competition can also distort both production and location decisions. Furthermore, these inefficiencies may be exacerbated by the fact that suboptimal firm location may lead to weakened agglomeration externalities. In other words, firms may be induced to

2 We thank David Brandon of The Pathfinders, a site selection consulting firm, for helpful conversations on these issues. He suggests that maintaining flexibility with respect to alternative energy sources and transportation logistics is most commonly important for firms' consideration of alternative site locations.

choose technologies that reduce agglomeration externalities, as did Caterpillar in the mid-1990s. This provides one potential explanation for why Ellison and Glaeser (1997) find less geographic concentration of U.S. manufacturing than one would expect.[3]

Our paper proceeds as follows. After a brief review of previous literature, section 3 presents our benchmark model of regional bidding for firms, but with fixed production capabilities of the firm. Section 4 expands the benchmark model to include prior exploratory research activities by the firm and thus allows for the endogenous determination of technical innovation. While agglomeration externalities are allowed in the model throughout, subsection 4.2 explicitly addresses their role and establishes equilibrium links between agglomeration externalities, specialization, and inefficiency. Section 5 offers an outline of the manner in which our results can be extended to an even broader class of economic environments that allow for the presence of extra-regional externalities. We provide concluding comments in section 6.

2. Previous literature

The literature on bidding for firms (see Wilson 1999, for a more complete summary) has often focused on how such bidding may enhance efficiency in firm location. Bond and Samuelson (1986) focus on a scenario of asymmetric information, where firms are uncertain ex ante about the productivity of a particular region, but the region knows its productivity with certainty. In such a scenario, competition for firms facilitates efficient location of firms, as initially offered subsidies (or tax holidays) signal the productivity of the region to the firm. Black and Hoyt (1989) address another inefficiency that may be alleviated by regional competition for investment. Their starting point is that most regions provide public goods and services (such as infrastructure) up to the level that average costs equal average benefits because of standard public finance methods of funding public goods. When the marginal cost of providing public services to a potentially relocating firm are smaller than the tax revenues the firm would yield for additional public services, regions can offer subsidies that reduce the distortion caused by the average cost pricing of public services. Thus, this leads to more efficient location of production across regions. King, McAfee, and Preston (1993) explore a bidding war between two regions for an investment where no participant in the bidding process (either the firms or the regions) knows the productivity of the region with certainty until the firm is located, but where subsequent relocation

3 In a related vein, Rauch (1993) develops a model showing how discriminatory pricing of land by regional developers over time can overcome the inertia of agglomeration externalities at traditional sites, provided the new sites have become inherently more efficient locations. This provides an explanation for how the location of agglomerating firms can change as underlying fundamentals change, whereas our model will suggest that firms may work towards mitigating agglomerative forces due to technology choices regardless of location.

of the firm is possible. The model yields efficient outcomes even when the regions first play a game in infrastructure investment (where greater infrastructure yields higher surplus from investment) prior to the bidding process. In a related vein, Davies (2005) shows that because regions would set inefficiently high taxes when firm investments have positive spillovers across regions, regional tax competition will lead to lower tax rates that may be closer to the efficient outcome and enhance national welfare.

In contrast to the literature noted above, our paper points out that there are potentially serious productive inefficiencies induced by regional competition. These inefficiencies affect not only firm location, but also production technology and the agglomeration externalities that accrue. Perhaps the most closely related previous literature to ours is work by Eaton and Gersovitz (1984), Brander and Spencer (1987), Bond and Samuelson (1989), and Janeba (2000). These papers model the bargaining process between a firm and a host region(s) and show that the possibility of renegotiation or even unilateral action by the region (such as expropriation) will lead to inefficient production decisions by the firm, either through a production process that is less capital intensive than would otherwise be optimal or by spreading excess capacity across competing regions. In contrast to our study, the inefficiency results presented in these papers rely on the existence of significant sunk costs that lock firms in to regions after location takes place. In addition, the scope of these results is limited to that of a two-region world, and, moreover, they do not address the issue of agglomeration externalities, which we find can play an important role in exacerbating inefficiencies.

A few theoretical papers have considered competition for investment in the presence of agglomeration externalities, including Kind, Knarvik, and Schjelderup (2000), Ludema and Wooton (2000), and Baldwin and Krugman (2004).[4] These papers focus on how agglomeration forces affect the intensity of tax competition and optimal tax rates across regions. In contrast, our focus is directed towards examining the manner in which agglomerative forces and regional competition for investment may jointly impact the location decisions of firms, as well as their choices regarding the development and implementation of production technology.

3. Regional competition for investment: benchmark model

In order to obtain an unobstructed view of the effects that regional investment competition may have on the development of firm production methods, we begin our formal analysis by considering a 'benchmark' model. In particular, the decision-making agents in our model are composed of a finite set I of firms

4 Head and Ries (1996) and Head, Ries, and Swenson (1999) examine the impact of both regional incentives and agglomeration externalities on firm investment decisions in an empirical setting. Both studies find evidence that agglomeration externalities attract investment, while Head and Ries (1996) find that agglomeration externalities enhance the effect of regional incentive policies.

and a finite set M of regions. Each firm selects a region in which to locate and a production plan to employ, while each region selects a profile of tax incentive packages that may be contingent on firm location and production decisions. Such tax incentive packages represent an extremely rich set of tax policy instruments that may include not only explicit tax rate policies, but also zoning regulations, pollution regulations, and labour practices (e.g., hiring quotas).[5]

To formally characterize the action spaces outlined above, we let $X = M$ denote each firm's space of location plans and let Y represent the space of all production/input employment plans, which we assume to be a closed subset of a finite Euclidean space. Thus $X^I = \times_{i \in I} X$ and $Y^I = \times_{i \in I} Y$ represent collective location and production plan space, respectively. It is also convenient to abuse notation and let $m(x^I) = \{I \in I \mid x_i = m\}$ for each $m \in M$ and $x^I = (x_i)_{i \in I} \in X^I$. In other words, $m(x^I)$ is the set of all firms selecting region m according to the location choice profile x^I.

We assume that regions have full flexibility in their tax policy design. Formally, a tax strategy for region m is a mapping $t_m : X^I \times Y^I \to \Re^I$ that specifies in-region firm taxation levels as a function of collective location and production behaviour. Naturally, we shall also assume regions are incapable of taxing firms outside of their jurisdiction. Let T_m denote the space of all such tax policies for region m and let $T^M = \times_{m \in M} T_m$ denote the space of all tax policy profiles. It may also be worth emphasizing that we place no differentiability or continuity constraints on taxation strategies. As a consequence, our general notion of 'tax strategy' effectively encompasses any regulatory device that may be used to control firm behaviour. For instance, pollution controls may be mimicked by the imposition of large lump-sum penalties for discharges in excess of specified standards.

To recap the sequence of play: regions begin by simultaneously announcing their respective taxation policies, and firms respond to these announcements by selecting both a region for their home operations and a production plan. A firm strategy is thus a tax-policy-contingent plan of action, that is, a mapping $s : T^M \to X \times Y$. The space of all such mappings is denoted by S and the space of firm strategy profiles is $S^I = \times_{i \in I} S$. Given a profile of firm and region strategies s^I and t^M, it follows that $t_m(s^I(t^M))_i$ represents the tax imposed by region m on firm i.

We also adopt an abstract formulation of region and firm preferences. Each region $m \in M$ is assumed to be endowed with a real-valued welfare function $\omega_m : X^I \times Y^I \to \Re$. So as to increase the transparency of our central conclusions and simplify our presentation, we shall assume that these welfare functions are

5 Our model follows the 'bidding for firms' literature, where it is 'assumed that regions are able to target subsidies and other tax breaks to mobile firms' and the central focus is 'whether the subsidies or tax breaks provided to firms are efficient in the sense that they lead to efficient firm location decisions' (Wilson 1999, 293.) This type of model contrasts with a separate 'tax competition' literature, where the set of available tax policy instruments is assumed to be limited such that changes in a region's tax policy towards one firm necessarily affects its tax policies towards other firms (e.g., uniform tax rates). In this strand of literature, inefficient equilibrium tax policies prevail.

independent of the choices made by firms locating outside region m; that is, if (x^I, y^I) represents the collective profile of firm actions, then ω_m is independent of x_i and y_i whenever $I \notin m(x^I)$.

The 'no extra-regional externalities' assumption described above may at first appear to be of questionable merit, as it is easy to envision scenarios in which a firm's actions may impact nearby firms, even if they are not located in the same region per se. However, we employ this constraint not because of its grounding in absolute reality, but rather because of the clear and unobstructed view it provides of the distortionary forces inherent to regional investment competition, particularly in regards to technological development and firm location. These same forces also persist in the presence of extra-regional externalities, despite the additional complexity that naturally emerges. See section 5 for further discussion on this point. As an aside, it may also be worth adding that the absence of extra-regional externalities can often be a less constraining assumption than it appears. For instance, recent micro-level analyses of industrial activity suggest that the impact that one firm's choices has on others often declines quickly in geographic space.[6]

Our model's formulation of regional welfare is quite general, with the possible exception of the assumed absence of extra-regional externalities. Indeed, it is capable of characterizing any preferences a region may have over firm behaviour: where they locate, whom they hire, types of jobs they offer, pollution they generate, as well as any regional agglomeration effects that may be present. Similarly, each firm $I \in I$ is endowed with a real-valued profit function $\pi_i : X^I \times Y^I \to \Re$, which we assume is also independent of extra-regional externalities; that is, π_i is independent of x_j and y_j whenever $x_j \neq x_i$. (Again, see section 5 for the implications of relaxing this constraint.) Note that this formulation allows for – but does not require – all forms of within-region profit effects, including agglomeration externalities. Finally, we assume that both region and firm preferences are quasi-linear in tax payments. Similar to King, McAfee, and Welling (1993), a region's post-tax welfare is the sum of the welfare it receives from both firm decisions and the tax revenues it collects. Likewise, a firm's post-tax profit function is the difference between the profits it receives from realized firm decisions and the tax payment it owes to its home region. Formally, if (s^I, t^M) represents a profile of firm and region strategies, m and I, respectively, represent a given region and firm, H represents all firms locating in region m, and n is the region in which i chooses to locate, then region m's post-tax welfare is $\omega_m(s^I(t^M)) + \sum_{j \in H} t_m(s^I(t^M))_j$ and firm i's post-tax profit is $\pi_i(s^I(t^M) - t_n(s^I(t^M))_i$. Note that our central insights can be re-articulated without the profit/welfare restrictions outlined in the paragraphs above. For instance, we could implement a more sophisticated non-linear

6 Henderson (2003), for example, finds that while a firm's productivity is affected by employment of other firms in the same industry in the same U.S. county, activity in nearby counties has no significant effect. Rosenthal and Strange (2003) find that new plants are attracted to zip codes that have greater own-industry activity, but that own-industry employment just five miles away has much smaller effects.

formulation of regional preferences for public good expenditures. Doing so, however, not only increases technical complexity, but also unnecessarily distracts from our intended focus on firm behaviour.

A profile (t^{M*}, s^{I*}) of region and firm strategies is an *equilibrium* if no region or firm can benefit from unilaterally altering its strategy. Such a profile is a *subgame perfect equilibrium* if the firm strategies are in equilibrium for every tax policy subgame.[7]

THEOREM 1. *Every subgame perfect equilibrium is Pareto efficient.*

Proof. Suppose there exists a subgame perfect equilibrium (t^{M*}, s^{I*}) that is not Pareto optimal; that is, there exists a set $K \subseteq M \cup I$ such that the agents in K can be made strictly better off without decreasing the payoffs of others. Since wealth can be reallocated between a region and the firms locating within the region, one can assume without loss of generality that there must exist a region $m \in K$, a set of firm's $J \subseteq K$, and payoffs $\omega'_m, (\pi'_j)_{j \in J}$ that strictly dominate the payoffs these agents would receive from (t^{M*}, s^{I*}) and that are feasible if the firms in J were to locate in m. Let $(y'_j)_{j \in J}$ denote production plans that would support these dominating payoffs. Let t'_m be a tax policy such that for each $j \in J$, firm j is ensured precisely the payoff π'_j, irrespective of the actions of others, as long as j locates in region m and adopts the production plan y'_j. Further assume that t'_m deters firms in J from choosing alternative production plans with a threat of high taxes. Likewise, assume firms outside J are deterred from entering m with a high tax threat. Recall that firm strategies are assumed to be in subgame perfect equilibrium. Thus, if m adopts the tax policy t'_m instead of t^*_m, it follows that precisely the firms in J will locate in region m and they will in turn select the production plans specified by $(y'_j)_{j \in J}$. By design, region m will then receive the payoff ω'_m. We conclude that t'_m is a strictly better response to (t^{M*}, s^{I*}) than is t^*_m, contradicting the assumption that (t^{M*}, s^{I*}) was a subgame perfect equilibrium. ■

This result reveals that while competition between regions for firms may well induce some reallocation of wealth between firms and regions, equilibrium behaviour will nonetheless lead to Pareto-efficient location and production decisions in our benchmark model. Indeed, such competition effectively induces regions to employ action-contingent tax policies that serve to internalize all of

7 Recall that firms observe tax policy prior to making their location/production choices; thus, every profile of tax policies effectively determines a distinct subgame within the comprehensive dynamic structure. Readers familiar with the literature on common agency problems may note similarities between the common agency model and the one we present. In particular, the regions of our model bear some resemblance to principals in the common agency model. (See, e.g., Dixit and Grossman 1997.) The two models are decidedly different, however, in that the common agency model has a single agent (akin to having only a single firm in our regional competition model), and this agent is allowed to receive payments from multiple principals (akin to a firm's being actively taxed by all regions, whether it locates within their jurisdiction or not).

the intra-regional externalities that might otherwise lead to Pareto inefficient firm decisions. For example, as part of an agreement to provide business incentives to Fujitsu Microelectronics, the city of Gresham, Oregon, required the firm to make substantial payments towards community service and training projects (*Oregonian*, 13 March 1997, F01). These projects included funding of a microelectronics training centre at a local community college; transportation, childcare, and housing programs for the firm's employees; training of low-income and at-risk workers for jobs with the firm; and efforts to meet ever increasing targets on the purchases of local goods and services. Obviously, all these are activities that the firm would not necessarily have done without the stipulations of its agreement with the city of Gresham, and some of the activities extend positive externalities to other firms in the region.

4. Competition for investment with endogenous technical innovation

4.1. Model extension and inefficiency result

The benchmark model outlined in previous section does not allow firms to alter their productive capabilities in any way prior to their commitment to a regional location. In many real-world settings, however, the willingness of a firm to relocate may well depend on its ability to change its production alternatives. For instance, current technology may dictate that profits be very dependent on the availability of highly skilled workers, while targeted R&D efforts may yield new technologies that substantially mitigate this dependence and render firms more geographically mobile. Similarly, the willingness of a region to actively lure a firm may depend on the firm's ability to adopt production methods that are to the region's liking (hire local workers, purchase local goods, pollute minimally, etc.). In this section we enrich our model by formally introducing a new exploratory research stage to the competition for firm investment game. The resulting structure will be referred to as an *ER/firm location game*. We shall use the phrase 'exploratory research,' ER for short, to refer to any of a broad range of activities that serve to enhance a firm's production possibilities or profitability. Such activities include traditional R&D efforts aimed towards the discovery of a new technical process that expands production possibilities, efforts to establish political connections and contacts in a region, efforts to obtain a clearer understanding for how best to employ region-specific resources, and so forth.

As discussed in the introduction, we shall assume that it is feasible for at least some such ER actions to take place *prior* to the public announcement of regional tax strategies. We do not mean to suggest that no production-expanding actions can take place after the release of tax strategies, but rather that, when they do, they will be referred to as part of the firm's production plan. Thus, the results of this section require only that firms have the option to carry out some ER activity prior to tax policy announcement. Indeed, if all such activity is constrained to take place after the release of tax strategies, then the environment is

that described by our benchmark model of the previous section and theorem 1 applies.[8] In regards to the proper modelling approach, we believe that allowing firms to choose ER actions first and having the regions respond subsequently is the correct sequence to model the real-world process of bidding for large discrete investment by firms. Firms considering a new plant location typically undertake internal discussion and a confidential location search before announcing the location set they are considering, after which these locations respond by developing their 'best' incentive package. It is worth further noting that, while we do not explicitly model the passage of time, it is implicitly a part of the movement between periods and thus actions taking place in different periods should be considered distinct. For instance, if a firm were to invest resources in the development of a new production process, this process might be more mature, functional, and profitable if the investment were to take place in period 0 as opposed to being delayed until period 2. Thus, the element of time may also present an incentive for firms to pursue ER activity prior to the announcement of regional tax strategies.

We now turn to the formal details of our model. Let us assume that each firm $I \in I$ is endowed with a set Θ_i of ER strategies from which to select. For each $\theta_i \in \Theta_i$ let $c_i(\theta_i)$ denote the cost the firm incurs from this ER strategy. For simplicity, we suppress the effects of risk and uncertainty and assume that ER action leads to certain outcomes regarding technical knowledge and its effects on firm profit and region welfare functions. Letting Γ denote the game outlined in section 1, this ER extension effectively indexes the game by $\theta^I = (\theta_i)_{i \in I}$, as profit and welfare functions alike are dependent on the 'state of technology,' and thus are in turn dependent on the ER strategies pursued by firms. Indeed, different states of technical innovation may lead to different levels of profit and productivity, different levels of agglomeration externalities, different levels of pollution, different levels of local employment, and so forth. This addition of an ER stage transforms our benchmark model into an ER/firm location game with the following sequence of play. In stage 0, firms simultaneously commit to ER strategies. These commitments are observable to players in all subsequent periods, so that choices in these periods may be made contingent on realized ER decisions. The profile of ER strategies θ^I generated in stage 0 induces the θ^I-subgame $\Gamma(\theta^I)$, which is identical to the benchmark structure outlined in section 1, except that each firm i's profits are reduced by $c_i(\theta_i)$. In particular, pre-tax welfare of region m is of the form $\omega_m(\bullet \mid \theta^I)$ and pre-tax profit of firm i is of the form $\pi_i(\bullet \mid \theta^I) - c_i(\theta_i)$.

One might expect that, since theorem 1 implies that subgame perfect equilibria induce Pareto efficiency on each θ^I-subgame, it must also follow that efficiency will prevail in the full ER/firm location game. Such expectations are unfounded, as we see below.

8 Of course one cannot appeal to theorem 1 if the absence of 'early' ER activity is voluntary.

TABLE 1
Pre-tax profit and welfare data

	Locate in region 1		Locate in region 2	
ER strategy	Pre-tax profit	Pre-tax welfare, regions 1,2	Pre-tax profit	Pre-tax welfare, regions 1,2
θ_1	3	3,0	0	0,1
θ_2	1	1,0	1	0,1

THEOREM 2. *Subgame perfect equilibria of the ER/firm location game may induce Pareto inefficiency.*

Proof. We demonstrate the validity of our claim by construction. So as not to distract with superfluous complexity, we construct a simple and intuitive example. This counter-example should not be interpreted as being representative of all ER/firm location games in which inefficiency prevails, as the classes of all such examples are many and varied. Note, also, that the example captures elements of the Mercedes Benz case study outlined in our introduction in the sense that tax incentives lure the firm into developing new production techniques that enable it to profitably locate in a region it would not otherwise have considered.

Assume there is a single firm with a single feasible production plan and two ER strategies (θ_1 and θ_2), and there are two regions (1 and 2) competing for this firm's investment. Given that there is a single production plan, pre-tax profit and welfare are simply functions of firm location and ER choices. Table 1 provides a summary of pre-tax profit and welfare data.

As table 1 reveals, θ_1 takes advantage of features specific to region 1 (highly skilled labour, for instance) and is not well suited to locating in region 2 (which may lack highly skilled labour). On the other hand θ_2 generates a production technology that has less peak profit potential, but is more location neutral.[9] (Note that each region receives zero welfare if it is unable to attract the firm to its location.)

It is easy to see that the equilibrium under the θ_1-subgame leads the firm to locate in region 1, pay 2 units profit in taxes, and thus earn only 1 unit of post-tax profit. Indeed, competition between the two regions will induce region 2 to offer, as a location incentive, the entire incremental surplus (the firm's profit plus incremental welfare) the firm would bring to the region. As this would yield a post-tax profit of 1, it is clear region 1 is free to tax the firm up to 2 units before the firm would consider locating in region 2.

9 One might feel compelled to include both a 'status quo' technology and a 'comprehensive' technology in which the best of both θ_1 and θ_2 are realized. However, if the status quo technology is strictly dominated by the alternatives described, there is nothing lost in its omission. Similarly, if the comprehensive technology is prohibitively expensive, it too may be neglected without loss of generality.

Equilibrium analysis under the θ_2−subgame is equally straightforward – competition will induce both regions to offer the entire incremental surplus to the firm, so that it will earn a post-tax profit of 2 at either location and both regions will receive a post-tax welfare of zero.

To conclude, the selection of θ_1 yields 1 unit of post-tax profit for the firm, while a selection of θ_2 yields 2 units of post-tax profit. Consequently, equilibrium behaviour leads the firm to select θ_2, inducing 2 units of aggregate surplus and payoffs that are Pareto inferior to those attainable when the firm selects θ_1 (and 6 units of aggregate surplus are generated). ■

The intuition underlying this result is straightforward. Investments in ER activity affect firm profits as well as region welfare, much like firm production plans. However, unlike a production plan that can be location specific, the state of a firm's technical innovation may potentially affect its profitability as well as its 'welfare productivity' in *all* regions. That is, while firms may choose different production plans at different locations, the constraints imposed by what is technologically feasible apply universally.[10] Such all-encompassing 'shadow externalities' affect equilibrium behaviour but cannot be internalized by tax policy, implying that inefficiency may inevitably follow.

The reader will note that the proof of theorem 2 did not require the presence of agglomeration externalities. Nonetheless, agglomeration externalities can very well play a central role, as we highlight in the following subsection.

4.2. Agglomeration externalities and induced inefficiency

In this subsection, we construct an ER/firm location game in which equilibrium behaviour leads firms to locate in separate regions despite the potential for substantial agglomeration benefits when locating in the same region. We structure the payoffs in our example to represent the following two-firm, two-region situation. Two firms could choose technologies (through ER strategies) so as to achieve maximal agglomeration externalities in a specific location, but when they do so, the surplus realizable in the alternative location is slight. This weakens the competitive bidding forces between the two regions and allows the region enjoying (potential) agglomeration externalities to tax away much of the firms' surplus. Alternatively, the firms could choose technologies that do not create strong agglomeration externalities, but instead generate a more uniform surplus across regions. Even though there is less pre-tax surplus created by the firm due to weakened agglomeration externalities from its technology choice, it cannot be as easily taxed away by the region. Thus, it is possible that the latter choice of technologies leads to higher after-tax surplus for the firms even

10 Of course, the quality and quantity of available inputs may differ across regions, so technology constraints may be more confining in some regions than others.

TABLE 2
Pre-tax profit and welfare data

	A locate in region 1 and *B* locate in region 1		*A* locate in region 1 and *B* locate in region 2	
ER strategies for firms *A,B*	Pre-tax profit for firms *A,B*	Pre-tax welfare regions 1,2	Pre-tax profit for firms *A,B*	Pre-tax welfare regions 1,2
θ_1,θ_1	3,3	7,0	0,0	1,1
θ_1,θ_2	1,1	2,0	0,1	1,2
θ_2,θ_1	1,1	2,0	1,0	2,1
θ_2,θ_2	1,1	3,0	1,1	2,2
	A locate in region 2 and *B* locate in region 1		*A* locate in region 2 and *B* locate in region 2	
ER strategies for firms *A,B*	Pre-tax profit for firms *A,B*	Pre-tax welfare, regions 1,2	Pre-tax profit for firms *A,B*	Pre-tax welfare, regions 1,2
θ_1,θ_1	0,0	1,1	0.5,0.5	0,1
θ_1,θ_2	0,1	2,1	1,1	0,2
θ_2,θ_1	1,0	1,2	1,1	0,2
θ_2,θ_2	1,1	2,2	1,1	0,3

though much lower agglomeration externalities and aggregate national welfare is generated.

So as to ensure a transparent equilibrium analysis, we again present an expository example stripped bare of unnecessary complexity. The example's structural components are defined as follows, assume there are two firms (*A* and *B*), each with a single feasible production plan and two ER strategies (θ_1 and θ_2) and there are two regions (1 and 2) competing for each firm's investment. Table 2 summarizes pre-tax profit and welfare.

The reader may note an asymmetry between region 1 and region 2 when both firms invest in θ_1. As previously noted, such asymmetry may be induced by differences in workforce quality, regional infrastructure, or the like. Given that the focus of this example is on the potential effects of agglomeration externalities, it is worth noting that such asymmetry may also be generated by the pre-existing presence of other firms generating agglomeration benefits within specific regions.

We begin equilibrium analysis of this example by considering the $(\theta_1\theta_1)$-subgame in which both firms develop technology θ_1. The aggregate surplus (firm profit plus region welfare) realized within region 1 is equal to $0 + 1 = 1$ when a single firm locates there but jumps to $3 + 3 + 7 = 13$ when both firms select the location for their operations, implying 'increasing returns to agglomeration' from joint location in region 1. As each firm adds only 1 unit of aggregate surplus to region 2 by choosing it as a location, it follows that competition between the two regions will induce region 2 to offer each firm this entire increment as a

location incentive and will induce region 1 to impose a 2-unit tax on each firm (leaving the firms with no more post-tax profit than is necessary to attract them). Thus, equilibrium on the (θ_1, θ_1)-subgame leads both firms to locate in region 1 and pay a tax of 2, leaving each a post-tax profit of 1, post-tax welfare of 11 to region 1, and post-tax welfare of 0 to region 2.

In the (θ_1, θ_2)-subgame, firms A and B always add 1 and 2 units, respectively, to the aggregate surplus of the region in which they locate. This 'constant returns to agglomeration' implies that every location combination can be realized in a (θ_1, θ_2)-subgame equilibrium and firms A and B will always attain post-tax profits equal to their full contribution to aggregate surplus (1 and 3, respectively), leaving 0 post-tax welfare for both region 1 and region 2.

The equilibrium roles of firms A and B in the (θ_2, θ_1)-subgame are those held by B and A in the (θ_1, θ_2)-subgame; that is, roles and post-tax profits are simply exchanged.

The (θ_2, θ_2)-subgame embodies 'decreasing returns to agglomeration' in the sense that each firm adds less aggregate surplus to a region the more firms that are present. (The incremental aggregate surplus of single firm is 3 when it locates in a 'vacant' region and is $5 - 3 = 2$ when it locates in a region that already houses the other firm.) Note that when each firm is locating in a different region, competition will induce regions to offer the entire 2-unit increment to their aggregate surplus as a location incentive. That is, each region will allow the firm to keep its full 1 unit of profit, plus the region will offer a -1-unit tax (i.e., a 1-unit subsidy) as further incentive to locate within its boundaries. Equilibrium on the (θ_2, θ_2)-subgame is thus realized when the firms locate in different regions and receive a tax of -1 from their home location, leaving post-tax profit of 2 for each firm and post-tax welfare of 1 for each region.

Given the subgame equilibrium behaviour derived above, the choice of θ_2 strictly dominates the choice of θ_1 for both firm A and firm B. Indeed, the (θ_1, θ_1), (θ_1, θ_2), (θ_2, θ_1), and (θ_2, θ_2) ER strategy profiles for (A, B) lead, respectively, to post-tax profits of (1,1), (1,3), (3,1), and (2,2). It thus follows that regional competition for firm investment will lure firms away from capitalizing on the substantial agglomeration externalities that are available – aggregate surplus of 13 can be attained if both firms choose θ_1 and locate in region 1. Instead, firms elect to develop an inefficient technology and locate in different regions: both choose θ_2, locate in different regions, and generate an aggregate surplus of only 3 for each of the two regions.

Although the model we have been using has focused on scenarios in which firms effectively have a single plant and must choose where to locate this plant, it is interesting to note that the example above can be used as a stylistic model of the Caterpillar case study noted in our introduction. Indeed, avoidance of the efficient (θ_1, θ_1) technology state also occurs in a subgame perfect equilibrium when firms A and B actually represent two plants owned by a single firm and the ER profiles simply represent an enumeration of four possible ER strategies for this firm.

4.3. Credibility, specialization, and the corresponding inevitability of inefficiency
While the constructive examples discussed in previous subsections are plausible abstractions, there is more we can say regarding the conditions under which we would expect inefficiencies to emerge. To do so, it is helpful to first construct a formal characterization of the aggregate effects induced by a firm choosing to locate within a particular region. Loosely, the *potential impact* firm i has in region m will be defined as the incremental effect of firm i locating in region m as measured by the sum of region welfare and firm profits generated within the region. In particular, this measure incorporates all effects of agglomeration externalities.

Take as given both the stage 1 subgame (i.e., given the profile of ER strategies for all firms) and the location and production decisions of all firms except a given firm i. We define the *potential impact* firm i has in a given region m as the largest impact firm i can have in region m under the given circumstances. To be more precise, let SUM1* equal region m pre-tax welfare plus the sum of all pre-tax profits earned within region m (including firm i) when firm i locates in m and chooses production plans that maximize this regional surplus (the plans of all other firms remaining fixed as well as firm i'*s* ER plan). Let SUM2 equal region m pre-tax welfare plus the sum of all pre-tax profits earned within region m (no longer including firm i) when firm i locates elsewhere. Then the potential impact of firm i on region m equals SUM1* minus SUM2. We further define the *first-best potential impact of firm i* as the highest potential impact firm i has among all regions. More generally, the r^{th} *best potential impact of firm i* is iteratively defined as the highest potential impact firm i has among all regions outside those in which the first- through $(r-1)^{\text{th}}$ best potential impacts are realized.

Finally, we define *credible equilibria* to be those subgame perfect equilibria in which no region offers incentives that exceed the respective firm's potential impact; that is, incentives must be credible. Of course, accepted incentives must be credible in any Nash equilibrium; thus, the credibility restriction is binding only for incentives that are offered but not accepted.[11] The narrowing of our focus to credible equilibria is, in practical terms, non-controversial. Indeed, it is unlikely that regions would make the effort to design tax incentives that they would never want to have accepted.[12]

11 It is worth noting that one cannot generally expect uniqueness in credible equilibria or in the firm payoff profiles (second-best potential impacts) they induce. Consider, for instance, an example with identical regions. Given any equilibrium, one can generate another through an exchange of regional 'roles' (assuming regions number more than one). Furthermore, it is straightforward to 'perturb' a regionally symmetric example with multiple equilibria into a regionally asymmetric model with multiple equilibria that yield multiple firm payoff profiles. In short, uniqueness requires the imposition of substantial restrictions on the nature of regional welfare and firm profits.

12 The common agency literature introduces the concept of truthful equilibria in which each principal offers a reward schedule that precisely mirrors the principal's own indifference surface. Credibility imposes no such constraint. In fact, continuity of regional welfare need not even imply continuity in credible equilibrium tax schedules.

We now have the machinery to articulate the following important result.

THEOREM 3. *If an* ER/firm *location game is in credible equilibrium, then each firm maximizes its second-best potential impact.*

Proof. We claim that in credible equilibrium the post-tax profit earned by a given firm on any stage 1 subgame (on or off the equilibrium path) must equal its second-best potential impact on the respective subgame. Indeed, if this post-tax profit were less than the second-best potential impact, then the second-choice region could unilaterally increase its post-tax welfare by altering the tax incentives it offers to induce the firm to locate there, contradicting the assumption that firms and regions are in equilibrium. On the other hand, credibility implies that the tax incentives offered by the second-choice region cannot exceed the potential impact of the firm in question in the second-choice region. As the post-tax profit in the first-choice region cannot exceed that which would be earned in the second-choice region (else the firm's first choice could reduce the incentives it offers and still induce the firm to locate there), the proof of our claim is complete.

As each firm seeks to maximize its post-tax profit and the above paragraph establishes that its post-tax profit for each ER strategy equals its corresponding second-best potential impact, each firm will thus invest in ER in a manner that maximizes its second-best potential impact. ■

Note that the occurrence of Pareto efficiency in equilibrium requires that, given the behaviour of others, each firm selects the ER strategy that maximizes its potential impact on its home region (wherein its first-best potential impact is realized). Appealing to theorem 3, we see that Pareto efficiency can be realized in a credible equilibrium only if for each firm the same ER strategy maximizes its first-best *and* second-best potential impacts. We argue that such circumstances are relatively implausible, especially when agglomeration externalities may exist. In order to establish this insight formally, let us consider the classical environment in which Θ^I is convex and both pre-tax profit and pre-tax welfare functions are concave in $\Theta^I \in \Theta^I$. We shall say that a firm's optimal ER strategy is *specialized* if, given the behaviour of other firms, it maximizes the firm's potential impact in one and only one region. (Thus specialization captures the notion that a firm's optimal ER strategy is customized for the particular attributes of one region and that this customization is less than ideal for other regions.) If such specialization is required for efficiency to be realized, then inefficiency can be expected to be the norm in all credible equilibria. Indeed, suppose efficiency requires that firm i's optimal ER strategy – call it θ_i^*, is specialized. Let m^* and m' denote the regions in which firm i's first- and second-best potential impacts are respectively realized given θ_i^*. Let θ_i' denote an ER strategy that maximizes i's potential impact in region m'. Specialization implies that θ_i' gives firm i a higher potential impact in region m' than does θ_i^*, and thus concavity of profit and welfare implies that $\lambda\theta_i^* + (1-\lambda)\theta_i'$ yields a strictly higher potential impact for firm i in region m'

than does θ_i^* for each $\lambda \in (0, 1)$. But for λ sufficiently small, the potential impact of firm i in region $m*$ is larger than its potential impact in region m'. It follows that firm i's second-best potential impact under the ER strategy $\lambda\theta_i^* + (1 - \lambda)\theta_i'$ exceeds that under θ_i^*. Theorem 3 thus implies that θ_i^* cannot be part of a credible equilibrium. This result is highlighted by the following corollary.

COROLLARY 4. *Credible equilibria induce inefficiency whenever efficiency mandates specialized production technology for at least one firm.*

Corollary 4 is particularly important for understanding the role of agglomeration externalities in the inefficiencies caused by regional competition. The development and fine tuning of the production methods for use in localities with strong agglomeration externalities are generally quite different from the efforts that would be pursued if a firm were to locate instead in a region where such externalities are modest or non-existent. Thus, the very tendency for agglomeration externalities to emerge may dictate that at least some specialization be present in order to realize Pareto efficiency. In the light of corollary 4, this fact in turn implies that efficiency cannot be credibly attained in equilibrium.

5. Extra-regional externalities

The no extra-regional externalities assumption was introduced when we first presented our 'benchmark' model at the start of our theoretical analysis. In this section, we discuss the implications of relaxing this assumption. We begin with the observation that the presence of extra-regional externalities renders theorem 1 irrelevant as a benchmark for gauging the distortionary effects of regional investment competition. Indeed, regional taxation policy does not provide a mechanism for internalizing all extra-regional externalities and thus granting 'first mover' status to regions is insufficient to ensure Pareto efficiency. As a consequence, the distortionary effects of regional investment competition cannot be measured by simply comparing 'regions move first' equilibria with 'firms move first' equilibria. In fact, equilibrium aggregate surplus in the latter setting could either be lower or higher relative to the former depending on the parametric specifics of the example at hand. That it can be lower was demonstrated in theorem 2's proof. That it can be higher is readily observed by constructing an example where a firm's equilibrium choice of exploratory research strategy coincidentally has a mitigating effect on the detrimental extra-regional externalities that are generated. (A numerical example is available from the authors upon request.)

Despite the disabling of theorem 1's benchmark status, as outlined above, the central insights produced in section 4 do continue to apply. In particular, theorem 2 remains valid as stated, irrespective of whether or not extra-regional externalities are allowed, and thus the potential for regional competition to induce an inefficient distortion of ER strategies continues to persist. Formulation

of the credible equilibrium concept in the presence of extra-regional externalities is significantly more complicated than in their absence. When such externalities exist, a firm's potential impact on a given region may depend not just on the heights to which the firm can raise the region's welfare, but also on the depths to which the region's welfare can sink as a consequence of the extra-regional externalities induced when the firm alternatively locates and produces elsewhere. Even so, credible equilibrium behaviour will continue to lead firms not to maximize their contributions to global or even regional wealth, but instead to maximize the potential impact it can have on the region that has the second-greatest incentive to secure the firm as a resident (with this incentive being defined relative to where the firm would otherwise locate). The spirit of theorem 3 thus persists, as this incentive to exploit the regional competition process to the firm's benefit can frequently be at odds with Pareto efficiency. Similarly, an analogue of corollary 4 will persist whenever extra-regional externalities fail to coincidentally align the pursuit of maximal second-best potential impact with the pursuit of Pareto efficiency and specialization (appropriately redefined to fit the extra-regional externalities context) is a necessary condition for efficiency.

6. Conclusion

Our paper has identified a new rationale for why regional competition may lead to inefficient outcomes: such competition may induce the development of inefficient production technology, as well as inefficient firm location and inefficient industry agglomeration. Regional competition gives firms incentives to develop (and potentially adopt) technologies that make alternative locations more competitive. This increased competitiveness between regions can often allow the firm to extract greater surplus for itself while at the same time decreasing the aggregate surplus that can be generated by the economy – an artefact of inefficient exploratory research activity, inefficient regional location, and a concomitant lessening of agglomeration externalities. Anecdotal evidence of recent U.S. examples discussed in the introduction highlight the surprising alterations in production technology that established firms will seek in response to regional competition for their investment.

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